SANITARY ENGINEERING

MOORE

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A PRACTICAL TREATISE

ON THE

COLLECTION, REMOVAL AND FINAL DISPOSAL OF

SEWAGE

AND THE

DESIGN AND CONSTRUCTION OF WORKS OF

DRAINAGE AND SEWERAGE

WITH A SPECIAL CHAPTER ON

THE DISPOSAL OF HOUSE REFUSE AND SEWAGE SLUDGE

AND

NUMEROUS HYDRAULIC TABLES, FORMULÆ & MEMORANDA

INCLUDING AN EXTENSIVE SERIES OF

TABLES OF VELOCITY & DISCHARGE OF PIPES & SEWERS

SPECIALLY COMPUTED BY

GANGUILLET AND KUTTER'S FORMULA.

BY

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WITH 534 ILLUSTRATIONS AND 70 LARGE FOLDING PLATES.

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PREFACE.

CONSIDERING the grave importance of Sanitary Engineering, it is remarkable that no book dealing with the subject as a whole has hitherto been issued. It is true that during recent years the contributions to Sanitary Science have been very numerous, testifying to the growing importance attached to the subject as our knowledge of it increases, but the various works published treat upon *parts* of it only, and in order to benefit by the researches of experts it becomes necessary to consult quite a library of books, dealing with the various branches of the subject ; a fact which was forcibly impressed upon me when preparing a course of lectures * at the School of Military Engineering, Chatham.

Convinced of the necessity for a comprehensive work that should deal with all the various matters which fall within the compass of modern Sanitary Engineering, I have prepared the present volume, in which I have endeavoured to bring together, in a concise and practical manner, such information as I believe is most needed for the guidance of those engaged in the important work of preparing and carrying out schemes for the efficient sanitation of our cities, towns and villages, whether as Engineers, Surveyors, Medical Officers of Health, Municipal Authorities, or Sanitary Inspectors ; in other words, a Book of Reference for all who are charged with the momentous duty of safeguarding and preserving the Public Health.

In view of the vast improvements effected in sanitary apparatus and appliances, and in the methods of sewage purification and disposal, refuse destruction, etc., special attention has been paid to these subjects.

* These were afterwards privately published for the use of the officers of the Royal Engineers in a volume entitled "Sanitary Engineering Notes," which is now out of print. Numerous Civil Engineers and Borough Surveyors, into whose hands copies had fallen, expressed their approval of the work, and suggested that the author should prepare an extended treatise on the subject.

As regards the final disposal of sewage the different systems described are allowed to speak for themselves, no one system having so far established its claim to universal acceptance, and special cases will always demand special treatment, although the progress that has been made during the last few years in the system of biological treatment tends to show that in this direction the ultimate solution of this troublesome problem will be found.

A considerable amount of space has been devoted to the subject of the Flow of Liquids in Pipes and Channels, including a sketch of the history of the development of the subject, based on the successive efforts of the earlier hydraulicians, and culminating in the modern formula of Darcy and Bazin, and still more recently in that of Ganguillet and Kutter, elaborated by their own extensive researches and mathematical skill.

One chapter is entirely devoted to Hydraulic Memoranda, and is followed by a collection of Hydraulic Tables specially arranged and compiled for this work.

The Hydraulic Tables for channels with segmental cross sections are intended to save labour in calculations, so that the drudgery which otherwise accompanies the solution of the formulæ for velocity and discharge is avoided. The advantage thus afforded cannot fail to be appreciated by any one who has ever attempted to calculate the discharge of pipes with varying depths of flow on the inverts: for this purpose the Tables give the values of the area of the cross section of stream for various depths on the inverts for all sizes of pipe from three inches to thirty-six inches, as well as the corresponding value of the $\sqrt{R}$.

A Table has also been compiled especially for use with Ganguillet and Kutter's formula, giving the values of S, $\sqrt{S}$, and $\left(a+\frac{m}{S}\right)$, for various slopes or inclinations from the vertical down to 1 over 21,120.

By these means, calculations for velocity and discharge and comparisons between the capabilities of discharge of different pipes with the same area of cross section of stream, can be readily made for any specified depth on invert.

The value of (c) can, in the case of Darcy and Bazin's formula, be obtained from the Table given for that purpose ; and if Ganguillet and Kutter's formula be employed, it may either be calculated by the help of the Tables for values of $\left(\frac{l}{n}\right)$ and $\left(a+\frac{m}{S}\right)$, or may be obtained graphically by aid of the Diagram on Plate LXI. This Diagram has also been specially prepared in the manner suggested by the writers of the English edition of Ganguillet and Kutter's work, and has been placed at the end of the book for convenience, and might with advantage be mounted on a board for use. The modified Form of the latter Formula and the Tables permit of (v) being found without first finding (c).

Examples of the methods of making a variety of calculations by the two formulæ above referred to are given, showing that Ganguillet and Kutter's, although apparently more complicated to use, is not really so when the aids to calculation afforded are properly utilized; this formula, also, as evidenced by the duplicate examples worked out, is always on the safe side, and should therefore, if for no other reason, be used in preference to that by Darcy and Bazin, and certainly to all other formulæ, which have been proved to be erroneous in principle and unreliable in results.

Extensive Tables of velocity and discharge for circular pipes and egg-shaped sewers have been specially compiled from Kutter's Formula at great labour and expense. Every effort has been made to ensure accuracy; but should any errors be detected, it is requested particulars may be sent to the publisher so that any necessary corrections may be made in further editions.

In the preparation of the work no effort has been spared to secure the latest and most reliable information, and I have to express my sincere thanks for the valuable help accorded me by various gentlemen having special knowledge of particular branches of the subject.

Amongst those to whom I am thus indebted I would mention: Mr. W. B. G. Bennett, A.M.I.C.E., Borough Engineer, Southampton, for the description and plates illustrating the sewerage works in that town; Mr. H. Percy Boulnois, M.I.C.E., Engineering Inspector to the Local Government Board, and late City Engineer, Liverpool, for much valuable information; Mr. W. Santo Crimp, M.I.C.E., F.G.S., for some of the plates on sewage disposal and other information; Sir Douglas Galton, K.C.B., F.R.S., for permission to include his paper on "The Lessons to be learnt from the Experimental Investigations upon the Purification of Sewage made by the State Board of Health of Massachusetts"; Mr. Charles Jones, M.I.C.E., Borough Engineer, Ealing, for special information and some of the plates of Destructors; Mr. W. L. Le Maitre, C.E., for the plates of the Mangotsfield Sewage Disposal Works;

Mr. E. Manville, M.I.E.E., for notes on the Shoreditch Destructor and Electric Light Installation; Mr. C. Chambers Smith, for the plates illustrating the Sutton Bacteria Tanks; Mr. Walter C. Tyndale, M.I.C.E., Sanitary Engineer to the War Office, for the plans of drainage at Warley Barracks; also to Colonel Ducat, R.E., Major Love, R.E., Colonel Slacke, R.E.; Mr. W. D. Scott-Moncrieff, C.E., Mr. Thomas Walker, M.I.C.E., Borough Engineer, Croydon, Colonel George E. Waring, M.I.C.E., and Mr. W. H. Gilbert Whyatt, A.M.I.C.E., Deputy Borough Engineer, Salford, for their help. Some further obligations are recorded in the text; and I have endeavoured in all cases to acknowledge where passages have been quoted from other works.

Finally, I have much pleasure in acknowledging the great assistance I have received from Mr. S. S. Platt, M.I.C.E., Borough Engineer, Rochdale, who has made many valuable suggestions and furnished original matter, which have added considerably to the practical usefulness of the work.

E. C. S. MOORE, Colonel, R.E.

(Late) Commanding Royal Engineers, Bermuda.

November 1*st*, 1898.

CONTENTS.

INTRODUCTION.

Necessity for the Speedy Removal of all Excrementitious Matter—Towns—Encampments—Zymotic Disease—Cause of, External—Channels for Introduction of—Typhoid Bacilli—Conditions of Growth—Object of Sanitary Engineering—Advance in Sanitary Science—Dry Refuse—Sewage—Definition of ... 1

CHAPTER I.—COLLECTION AND REMOVAL.

Adequate System Necessary—The Combined System—Modification excluding Subsoil Water—Absolutely Separate System—Partially Separate System—Shone's Hydro-Pneumatic Ejector System—The Liernur System—Interception—Cess-pits—Soak-pits—Middens—Pails and Tubs—Earth Closets—Temporary Latrines—Cost of Removal of Excrement—Comparison of Systems 3

CHAPTER II.—SEWERAGE.

Choice of System—Definitions—Drains and Sewers—General Principles—Levels—Depth of Sewers, etc.—Manholes—Straight Lines between Manholes—Valves—Penstock Chambers—Ramps—Outfalls—Storage Tank—Inverted Syphons—Syphon Drops — Pumping or Lifting—Shone's Hydro-Pneumatic Ejectors—Night Soil Depôts and Flushing Tanks—The Supplementary High-Pressure Water Supply—Sewage Lifting Apparatus—Adams's Patent Automatic Sewage Lift—Draining by Deflection, Lynde's Principle—Junctions not to be at Right Angles—Cross Sections—Area of—Estimate of Amount of Sewage—Water Supply as Guide — Admission of Rainfall — Exclusion of Flood Water—Estimate of Sewage and Rainfall Combined—Gradient and Velocity of Flow—Minimum Fall—Maximum Fall—Table of Discharge of Pipes—Flushing—Necessity for Calculating Discharges—Table of Sizes of Sewers, Combined System—Sewerage of Rangoon, Rochdale, Southampton—Construction and Materials, see Chap. VI. 11

CHAPTER III.—THE FLOW OF LIQUID IN PIPES AND OPEN CHANNELS.

Proper Selection of Section Necessary — Modern Practice—Smaller Channels More Economical and Efficient—Knowledge Required by Sanitary Engineer—Including Water Supply—Modern Formulæ: How Obtained—Galileo's Difficulties in Investigating the Laws—Castelli—Torricelli—Guglielmini—Grandi—Pitot—Bernouilli—Brahms—The Hydraulic Mean Radius—Chézy—General Formula of—Dubuat—Venturi—Coulomb—De Prony—Eytelwein—Neville's Modification of Dubuat's Formula—Kühlmann and Weisbach—Humphreys and Abbot—Danger from Employing Incorrect Formulæ—Darcy and Bazin's Formula—Their Investigations—Modification to English Measure and Notation—Pipes Running Full—Value of (ζ)—Size of Pipe for Special Discharge—Open

CHAPTER III.—THE FLOW OF LIQUID, ETC.—(*continued*).

Channels—Two Interpolated Coefficients—Ganguillet and Kutter's Formula—Their Investigations—Value of (*c*) and Constants (*a*), (*l*), and (*m*) in English Measure—Six Categories—For Value of (*n*)—Graphic Solution—Preparation of Diagram—Table of Off-Sets for (*n*) Lines—Method of Finding (*v*)—Also Maximum Velocity—Value of Labour-saving Tables—Relative Accuracy of Formulæ—Difficulty in Selecting Value for (*n*)—Flynn's Modification of Kutter's Formula—Author's Form—Table of Ordinates for Slope Curves 37

CHAPTER IV.—HYDRAULIC MEMORANDA.

Pressure at any Point in a Liquid—Head of Pressure—Head of Elevation—Loss of Head—Reduction of Velocity through Pipe—Resistance of Pipe—Minor Losses—Loss due to Velocity — Orifice of Entry — Elbow — Bends Angular — Circular—Sine of Inclination—Heads in Main—Hydraulic Gradient—Direction of Main—Wetted Perimeter and Hydraulic Mean Depth—Syphons—Egg-shaped Sewers, Ordinary Form—Proportions for—Hydraulic Table for—Modified Form of Egg-shaped Sewer—Proportions of—Hydraulic Table for—Jackson's Peg-top Section—Proportions for—Hydraulic Table for—Discharge of Water over a Notch or Weir—To Raise a River a certain Height by a Weir—Gauging a Stream—Triangular Notch—Separating Weirs—Measurement of Velocity of Stream—Relation between Mean and Surface Velocities (Bazin)—Mean Velocities from Maximum Surface Velocities (Bazin)—Destructive Velocities (Kutter)—Abrading and Transporting Power of Water 57

HYDRAULIC TABLES.

This section contains an entirely new and extensive series of **TABLES** giving the **VELOCITY** and **DISCHARGE** of **SEWERS, PIPES** and **CONDUITS (CIRCULAR** and **EGG-SHAPED)**, specially computed for this work by **GANGUILLET** and **KUTTER'S FORMULA**; together with a large number of other Tables of great assistance to Engineers (*vide* List of Tables, pp. xviii—xx) ... ...81—174

CHAPTER V.—APPLICATION OF FORMULÆ OF DARCY AND BAZIN, AND ALSO OF GANGUILLET AND KUTTER.

Drainage—With Glazed Stoneware Pipes—Example I.—Size and Self-Cleansing Capacity—Example II.—Slopes—Example III.—Angular Section—Example IV.—Water Supply with Cast-iron and Wrought-iron Pipes—Example V.—Services—Example VI.—Mains—Example VII.—Horse-power 175

CHAPTER VI.—CONSTRUCTION AND MATERIALS.

Portland Cement—Contraction of—Expansion of—Cement Store-house—Hydraulic Lime—Sand—Mortar—Grout—Concrete—Bricks—Description of Pipes Used—Stoneware "Tested" Pipes, Strength of—Maximum Diameter—Thickness of—Length of—Forms of—Granite Stoneware Sanitary Pipes—Special Connections—Standard Access Pipes—"Loco" Inspection Shaft—Concrete Pipes—Sizes of—Joints: How Made—Saddle-joints—Stanford's Patent Joint—The Double Seal—Doulton's Self-adjusting—The Archer Patent Joint—Robin's—Hassall's—Green's Patent "True-invert" Pipe—Paragon Pipes—The "Loco" Drain Joint—Ames and Crosta Pipe Joint—Single Seal and Double Seal—Sykes' Patent Joint—Constructing Drains—Preliminary Arrangements—Excavating Trenches—Pipe Laying—The "Loco" Drain Badger—Depth—Method of—Cause of Breakage

CHAPTER VI.—CONSTRUCTION AND MATERIALS—(*continued*).

of Stoneware Pipes—Cause of Chokage—Temporary Obstruction: How Removed—Drains of Larger Capacity—Brickwork—Bricks for Sewers—Egg-shaped Sewers—Formulæ for Sectional Area and Cubic Yards of Brickwork—Some Methods of Construction—Egg-shaped Sewers at Southampton—Details of Construction—Centering—Pipe Drains—Surface Water Drains—Invert Blocks—Concrete—Adequate Foundation Required—Manholes—Rock Concrete—Junction Pits—White Enamelled Channels—Air-tight Covers—Jones's—The "Loco"—Hellyer's—Cast-iron Drain Pipes—Weight and Thickness of—Material for—Coating for—Dr. Angus Smith—Bower Barff—Scott-Moncrieff's System of Cast-iron Drainage—Glass Enamelled Cast-iron Drain-pipes—Joints—Turned and Bored Sockets—Flexible Joint—Vertical Soil-pipes—Lead—Cast-iron—Glass Enamelled—Weight of—Position of—Size of—"Loco" Deflector Bend—Joints in Iron Pipes—Rust Joint—Trap at Foot of—Syphons—Outfalls: Cast-iron—Steel—Lead Pipes—Waste Pipes—Connection with Stoneware Pipe—Variety of Joints—Wrought-iron Piping—Drains under Buildings—Stables: How Drained—Laundries: How Drained 199

CHAPTER VII.—VENTILATION.

Sewers—Decomposing Sewage Dangerous—Ventilation and Traps—Duty of Local Authority to Ventilate—Points to be Observed in Sewer Ventilation—Simple Ventilation—Manhole Cover, Oval Ventilating—Elliott's Patent Air Inlet for House Drains—Ventilating Shafts—Special Arrangements for Dealing with—High Shafts—Other Methods—Adams's System—Charcoal Ventilator—Chemical Deodorizer—Mr. W. Santo Crimp's Experiments—Keeling's Gas Destructor—Adams's Ventilating Shaft—The "Reeves" System—Chart showing Atmospheric Forces which Influence the Formation of Sewer Gas—Mr. William Brown's Experiments—Ventilation of the Sewers of Edinburgh and Leith—Webb's Patent—Extractors and Destructors—Water Injection—Machinery—Shafts for Ventilating, Size of—Pipes for—Rust Pockets—Intercepting Traps—Single Drainage—Combined Drainage—House Drainage—Soil-pipe, Ventilation of—Alternative Method—Fresh-air Inlet to Soil-pipes—Cregeen's Air Inlet—Beaumont's Valve—Cowls: Kite—Boyle—Hellyer—Buchan—Banner—Weaver—Sugg's Patent Continuous Up-draught Ventilator—Wastes from Sinks, Baths, etc.—Ducketts' Self-cleansing Channel Gully—Mooney's ditto—Sykes' Disconnecting Slipper—Outside Gullies—Ventilation of Drains of Enclosed Blocks of Buildings—Drains under Buildings—Admission of Surface Water to Foul Drain—Public Conveniences (underground) 261

CHAPTER VIII.—TRAPS.

Object of—Water-lock—Failure of—Traps Necessary Evils—Position of—Good Flush Necessary—Form of—Mason's Traps—D-Traps, Self-cleansing—Examining Eyes—Special Forms—Buchan's—Weaver's—Hellyer's—Stiff's—Ingham & Sons'—The Kenon—Light's Quickflush Trap—Sewer Gas Interceptor with Sykes' Air-tight Screw—Main Intercepting "Loco"—Sykes' Patent Interceptor—Cast-iron Disconnecting Trap—"Loco" Deflecting Traps—Mooney's Self-Cleansing Gully and Block—Sankey's Deep Intercepting Gully—Grease Traps—Hellyer's—The Patent "Loco" Grease Box—The Author's Pattern—Winser's Flushing Rain Grease Trap—Self-closing Traps—Gullies for Stables—Cottam & Willmore's Sanitary Gully—Broad's Stable Gully—Flaps—Ball Tide Valve—Traps for Sinks—Bell Trap—Jennings's—Syphon—Tye & Andrew—The Anti-D-Trap—Double Seal 289

CHAPTER IX.—APPARATUS.—LATRINES AND W.C.'S.

Position of—Great Variety of—Latrines—Doulton & Co.— Bowes, Scott, & Western — Jennings — Macfarlane — Jennings's Patent Automatic Latrine — Water Closets—Clean-water Closets—Pan Closet—Valve Closet—Jennings's —Underhay's — Tylor's — Valveless Closets — Wash-out Closets — Wash-down Closets—Doulton's "Simplicitas"—Ducketts' Wash-down Pedestal—Shanks' "Compactum" — Twyford's, with After-flush Chamber — The "Twycliffe" —The "Metropole"—Pedestal Closets—Connection with Soil-pipe—Ventilating Openings—The "Self-ventilating Safety" W.C. Trap—Author's Patent—Hellyer's "Bracket Hygienic"—The Closet of the Century—The Scientia—Disinfecting Apparatus for W.C.—Attention to Cleanliness Necessary—Slop-Water Closets—Ducketts' Slop-Water Closets—Multiple Closets—The Perfect Slop-Water Closet—Advantages over Clean-Water Closets—Clean-Water Supply to Closets, Slop Sinks—Valves under the Seat—Water Waste Preventers and Regulators—Waste-preventing Valves fixed in Cisterns—Separate Waste-preventing Cisterns fixed in each Water Closet—Valves—Syphons—Doulton's —Winn's Patent "Acme" Syphon Cistern—Crapper's—Twyford's "National" —The "Westminster"—Shanks'—The "Stafford" Syphon Cistern—Ducketts' A 1 — Waste-preventing Regulators Fixed under Seats — Tylor's Waste Preventer—Underhay's Oil Brass Closet Regulators 309

CHAPTER X.—APPARATUS—(*continued*). URINALS, LAVATORY FITMENTS, ETC.

Urinals, Provision of—Difficulties Involved—Three Classes—I. Urinal Stalls—Backs and Divisions—Sparge Pipe—II. Trough Urinals—Doulton's Flush-down—Twyford's Flush-out—III. Interior Urinals—Beck & Co.—Doulton & Co.—Jennings's — Hellyer's—The Holborn — Tylor's — Public Conveniences, Underground—Jennings's—Bolding's "Laydas" Circular—Automatic Flushing Apparatus—Jennings's—Crapper's—Twyford's—Merrill's—Slop Sinks—Dent & Hellyer—Doulton & Co.—Tylor & Son—Scullery Sinks—Ducketts' Sink Fittings — Pantry Sinks — Baths — Copper—Zinc — Iron—Slate—Porcelain—Wastes—Lavatory Basins—The Tip-up Basin—The "Loco" Lavatory Basin—Valves — Jennings's — Hellyer's — Lead Safes — Hinged Flaps — Washers, Plugs, and Wastes—Flushing Drains—Water for Flushing—Syphons—Field's—Adams's—Field's 1889 Patent—Miller's Automatic Flushing Syphon—Velocity Diagrams—Ducketts' Automatic Tippers—Manholes—Movable Tanks —Fire Engine—Order of Flushing 335

CHAPTER XI.—SURFACE WATER COLLECTION.

Surface Water—How Collected—Eaves Gutters—Down Pipes—Joints—Down Pipes not to be led into Drains for Foul Water—Along Surface Channel—From Roads —Surface Gutters, Fall of—Surface of Road—Drains—Catch-pits—Separate System—Combined System—Mason's, or Dip Traps—Lowe's Trap—Newton's Street Gully—Turner-Croker's Gully—Crosta's Patent—Cartwright's Stench Trap—Hagen's Duplex Cesspool Trap—Dean's—The Grosvenor—Ducketts' Gully—Lovegrove's Patent—Sykes' Street Gully—Stokes' Gully Trap—Sykes' Yard Gully—A Buddle Hole—Liability to become Unsealed—Admission of Waste Pump Water—Also Surface Water to Foul Drain 375

CHAPTER XII.—SUBSOIL DRAINAGE.

Source of Moisture—Injurious Effects of Wet Soils—Report of Commission—Depth of Drains—Arrangements of—Fall—Distance between—Direction—Outlets—Silt Basin—Use of Sumps—Flushing—Air Drains—Clay Soils—Drainage under Foundations—Buildings—Magazines—Surrounding Site—Special for Footings—For Peaty Soil—Railway Embankment, Drains through Foot of—Execution—Trenches, Depth of—Ordinary Tools—Machines—Bottom to be Currented Accurately—Material and Size of Pipes—Quality—Junctions—Method of laying—Filling in Trench—Stones over Pipes—Fine Earth—Object of—Stone, or French Drains—Hand Packing—Brushwood—Boggy Land—Failure of Drains—Silt—Vermin—Roots of Trees—Roads—Plan of Drains—Special Measures for Underground Buildings—Colonel Moore's Process for Curing Damp Walls—General Remarks on—Advantages of 385

CHAPTER XIII.—SANITARY NOTES.

Made Ground—Natural Soil—The Influence of Subsoil Water on Health—Admission of Steam to Sewers—Drain Testing—House Inspection—Hydraulic or Water Test—Drain Plugs—Jones's Pipe Stopper—Peppermint and Smoke Tests—Instructions for—The Eclipse Smoke Generator—The Watts Asphyxiator—The Tyndale Asphyxiator—The Champion Fumigator—The "Banner" Drain Grenade—Kemp's Drain Tester—Pain's Smoke Cases or Rockets—Burnet's Smoke Drain Tester—Analysis of Subsoil Water—Old Culverts to be Destroyed—Water Supply Pipes to be Disconnected from Sewer—Examination of Drains—Flushing—Water Mains to be Periodically Tested—Subsoil Drainage—Sites of Infectious Diseases to be Recorded—Disinfectants—Powerful or Germicides—Weak—Antiseptics—Deodoriser but not an Antiseptic—Aërial Deodorants—Disinfecting Powders—Liquids—Use of—Izal—Formalin—"Reevozone"—Condy's Fluid—Chloride of Lime—Calvert's Carbolated Creosote—Method of Application of Disinfectants—Process recommended by Drs. Dupré and Klein—Sanitary Maxims 407

CHAPTER XIV.—SEWAGE DISPOSAL.

Efficient Disposal Necessary—Standard of Purity—Various Systems—Dry Earth—The Sea, or Tidal Estuary — Influence of Tidal Currents on Irrigation—Researches of Dr. Voeckler—Mr. Warrington's Report—The Theory of Nitrification—The Distribution of the Nitrifying Organism in Soil—Settling Tanks—General Form of—Dundrum Tanks—The Dortmund Settling Tank—Broad Irrigation — Beddington Irrigation Farm — Distribution over Land—Ridge and Furrow System—Preparation of Land—Acreage—Crops Suitable—Capacity of Land—Filtration (Intermittent Downward)—Constant Aëration Required—Filters—Keirby's Patent Mixer—Precipitating Agents— Variety of Processes—Lime—The Amines—Lime and Sulphate of Iron—Lime and Alumina—The Glasgow Sewage Works—Spence's "Alumino-ferric"—Richmond Main Sewerage Board Works—The Natural Purification Company's System (Cosham's Patent)—The "Universal" Sewage Purification Company (The "Ives" Patent)—Oxynite—The A. B. C. Process—The International—Mangotsfield Sewerage and Sewage Disposal—Analysis of Effluent, &c.—Conder's Sulphate of Iron—The Hermite—Dale's Muriate of Iron—Massachusetts, Experimental Investigations by the State Board of Health of — Relations of Sewage and the Effluents from Chemical Precipitation to the Growth of Bacteria and Algæ—Conclusions—Electrolysis—Webster's Process for the Electrical Purification

CHAPTER XIV.—SEWAGE DISPOSAL—(*continued*).

of Sewage—Reports on—Bacteriolysis—Massachusetts Experiments, paper by Sir Douglas Galton, K.C.B., &c.—Lowcock's Filter—Scott-Moncrieff's Cultivation Filter Bed—Waring's Filter—Summary of Results obtained by Colonel G. E. Waring, junr.—Discussion—Mr. Dibdin's Experiments—Bacteria Tank at Sutton—Method of Applying the Sewage—Action of the Filter—Purification of Sewage by the Oxygen System—The Scientific Principles of Sewage Purification—The Oxygen System of Sewage Purification—Trade Effluents—Tanks—Adaptability of Existing Works for the Oxygen System—The Cost—The Garfield Filter—The Salford Experiments—Septic Tank System—Aërated Bacterial Self-Acting Filter (Colonel Ducat's Patent)—The Purification of Sewage by Bacterial Oxidation and Forced Aëration, by Colonel G. E. Waring, junr., M.I.C.E.—The Scott-Moncrieff System—The Classification of the Organisms which Purify Sewage—Their Capacity to carry on the Work of Purification—The Latest Developments of the System—After Liquefaction takes Place—Sewage Disposal at Barking, Beddington, Mangotsfield, Bristol, Chichester, Crossness, Glasgow, Hendon, Hitchin, Ipswich, Newport (U.S.A.), Nuneaton, Richmond, Salford, Southampton, Sutton, Wimbledon, Wolverhampton, &c., &c. 426

CHAPTER XV.—DISPOSAL OF SLUDGE AND HOUSE REFUSE.

House Refuse—Collection of—Dr. Young's Reports on Methods of Collection and Disposal of House Refuse in London—Cost of Removal—Mechanical Sorting—Disposal of Sludge—Methods of—Evaporation—Wimbledon Sludge Disposal Works—Mechanical Treatment—Weight of Sludge Cake—Sludge Manure—Johnson and Hutchinson's Pneumatic System—Destruction—General Remarks on Refuse Destructors—Cost of Construction of—Cost of Destruction—Analysis of Ashbin Refuse—Utilisation of Waste Heat for Raising Steam and Electric Lighting—Power Available for these Purposes—Two Classes of Destructors—Fryer's Patent—Mr. Jones's Improvements—Fume Cremator—Ealing, Disposal of Sewage Sludge and House Refuse—Battersea—Liverpool—Leyton—Hereford—Rochdale—Salford—Horsfall Furnace—Warner's Perfectus Destructor—Bennett-Phythian High Pressure Destructor—Beaman and Deas Destructor—The Meldrum Destructor—Artificial and Forced Draught for Steam Boilers—Power required for Forcing Combustion—Boilers for use with Destructors—Babcock and Wilcox Boilers—Recent Sanitary Works at Southampton—Combined Electricity and Dust Destruction Works, Shoreditch—Results obtained at Shoreditch—Feed Thermal Storage—Chimney Shafts for Destructors—Dimensions of—General Rules and Formulæ—Foundations for—Depth of Foundations Footings—Wind Pressure—Pressure on Solid Bodies of Various Forms—Stability of Chimneys—Cost of Chimneys—Cardiff Report 529

INDEX 605–620

LIST OF PLATES xv

LIST OF TABLES xviii

LIST OF AUTHORITIES CONSULTED xxi

LIST OF MANUFACTURERS WHOSE SPECIALITIES ARE REFERRED TO xxv

LIST OF PLATES.

PLATE — FACING PAGE

I.—Temporary earth closets and shed: Sections and Plan... 8
II.—Ramps in sewers: Sections, Plans, and Details ... 12
III.—Junction between high and low level drains: Longitudinal Section and Plan 14
IV.—Method of sewering steep streets, Rochdale: Section 14
V.—Sewer outlet on tidal river or seashore: Plan and Sections 16
VI.—Sewer outlet on sea coast or tidal river, where there is a steep cliff of rock: Section 16
VII.—Manhole with 21 in. sluice, as used on the Metropolitan Sewerage Works: Plans and Sections ... 18
VIII.—Syphon arrangement for sewers: Section 18
IX.—Warley Barracks Drainage: General Plan 20
X.—Sewer outfall: Plan of Penstock Chamber, with Details 20
XI.—Rangoon Sewerage on Shone's hydro-pneumatic system: Plan of the city of Rangoon, showing sewage and compressed air mains, ejector stations, air compressing stations, &c. 22
XIa.—Sewerage of the Eastern District of Southampton: Cross sections of egg-shaped sewers and circular pipes 232b
XII.—Cast-iron drainage: Socket pipes and connections for house drains 248
XIII.—Cast-iron drainage: Lever locked cast-iron inspection chambers and gullies 248
XIV.—Cast-iron drainage: Plans and Sections, showing complete system as fixed 250
XV.—House drainage: Ventilation of 280
XVI.—House drainage: False drains 280
XVII.—House drainage: Use of junction pits 286
XVIII.—House drainage: Showing arrangement to be adopted when drains are carried under houses ... 286

PLATE FACING PAGE

XVIIIA.—Sewer Ventilation: Sections of manholes showing Reeves apparatus 288F
XIX.—Trough closets: Elevation and Section 310
XX.—Slop-water closets: arrangements of 324
XXI.—Slop-water closets: arrangements of 326
XXII.—Flush-down urinal: Elevation and Section ... 338
XXIII.—Trough urinal: Elevation and Section 340
XXIV.—Urinal basin range: Elevation 342
XXV.—Underground conveniences: Plans of a convenience situated in the centre of a busy thoroughfare ... 342
XXVI.—Underground conveniences: Sections 344
XXVII.—Underground conveniences: View of the "Radial" urinal with flushing tank and connections ... 345
XXVIII.—Sinks... 354
XXIX.—Subsoil drainage 390
XXIXA.—Sketches showing application of Reevozone charges for purifying air in sewers 422
XXX.—Dortmund Sewage Tank: Plan and Sections ... 434
XXXI.—Beddington Irrigation Farm: Plan 436
XXXII.—Hitchin, Herts, Irrigation Farm: Plan 438
XXXIII.—Glasgow Sewage Works: Plan of Machinery Building 446
XXXIV.—Cosham's Circular Automatic Precipitation Tank: Section and Plans (Natural Purification Co.'s Process) 452
XXXV.—Ives's Circular Precipitation Tank: Plan (Universal Purification Co.'s Process) 454
XXXVI.—Ives's Circular Precipitation Tank: Sections ... 454
XXXVII.—Mangotsfield Sewage Disposal Works, Bristol: Plan 458
XXXVIII.—Mangotsfield Sewage Disposal Works, Bristol: Sections 458
XXXIX.—Mangotsfield Sewage Disposal Works, Bristol: Plan of Outfall Field showing Land Drainage, and General View of Works 462
XL.—Treatment of Sewage by the iron process: Details and arrangement of plant 464
XLI.—Lowcock's Patent Filter: Section and Plan of sludge tank, precipitating tanks, and filter beds for the treatment of 100,000 gallons of sewage per day 478
XLII.—Colonel Waring's Filter: Straining and aërating tanks 486
XLIIA.—Sutton (Surrey) Sewage Disposal Works: General Plan 496

PLATE FACING PAGE

XLIIB.—Sutton (Surrey) Sewage Disposal Works: Plans and Sections of Bacteria Tanks 496D
XLIII.—Septic Tank Filtration: Plan of the septic tank plant at Belleisle for dealing with the sewage of Exeter 512
XLIV.—Ditto. Section showing arrangement of filtering material 512
XLV.—Ditto. Automatic arrangements 512
XLVI.—Aërated Bacterial self-acting filter; type for village of 2,000 inhabitants: Plant and Details... ... 514
XLVII.—Aërated Bacterial self-acting filter: Sections and Plan 514
XLVIII.—Aërated Bacterial self-acting filter: Sections, etc. ... 514
XLIX.—Vertical Section of Sewage Purification Plant, designed by Colonel Geo. E. Waring, M.I.C.E. ... 520
L.—Sludge Presser (Messrs. Johnson & Co.) 536
LI.—Sludge Disposal Works at Wimbledon: Plan, Sectional Elevation, and Cross Section of the Plant 538
LII.—Elevation and Plan of Sewage Disposal Works for a small town... 540
LIII.—Fryer's Patent Destructor Furnace: Elevations and Sections 546
LIV.—Ealing Southern Sewage Works: General Plan ... 546
LV.—Ealing Destructor, with Fume Cremator attached: Section 548
LVI.—Fume Cremator as in use at Ealing: Plan and Sections 548
LVII.—Twelve-Cell Destructor and Fume Cremator, Battersea 550
LVIII.—Ditto ditto. Sectional Elevation 550
LIX.—Warner's "Perfectus" Destroyer: Section... ... 554
LX.—The Beaman and Deas Destructor, with Babcock and Wilcox Boiler: Section and Plan 556
LXA.—Chimney Shaft, Southampton Destructor Works: Elevation and Section 572
LXB.—Southampton Main Sewerage: General Plan ... 582
LXI.—Diagram for the determination of the graphic value of (*c*), Ganguillet & Kutter's Formula *at end of book*

LIST OF TABLES.

PAGE

1. Discharge of different sized pipes, *running full*, at different velocities ... 34
2. Combined system, showing the quantity of paved or covered surface from which circular sewers (with junctions properly connected) will convey away the water coming from a fall of rain of one inch in one hour, with house drainage 35
3. Combined system, showing the size and inclination of main house drains for given surfaces, and the number of houses of either rate thereon, calculated from Mr. Roe's table for a fall of rain two inches in the hour 36
4. Darcy and Bazin, values of the two interpolated co-efficients (α) and (β), with their logarithms 46
5. Ganguillet and Kutter, six categories of value of (n)... 48
6. Off-sets for the (n) lines 50
7. Values of constants (a), (m), and (l) 51
8. Giving the value of (k) for use in Flynn's modification of Kutter's formula 53
9. Slope curves (Plate LXI.). Ordinates in inches 55
10. Orifices, Co-efficient of contraction for—Values of (m) 60
11. Table of co-efficients of velocity of discharge for rectangular orifices, where the height of the orifice is less than the width for different kinds, as deduced by Rankine from experiments by Poncelot and Lesbros ... 61
12. Loss of head due to orifices in Table 10 61
13. Loss of head at elbow 62
14. Loss of head for circular bands (Weisbach) 63
15. Loss of head for rectangular section 63
16. Loss of head for circular section (Hurst) 63
17. Egg-shape sewers (Old form)—Area wetted perimeter and hydraulic mean depth when flowing at various depths 66
18. New "Egg-shape" ditto ditto 67
19. Jackson's peg-top section ditto ditto 67
20. Mean velocities from maximum surface velocities (Bazin)—Value of (c) ... 76
21. Safe bottom and mean velocities in channels (Dubuat) 76
22. Transporting power of water 78
23. Collection of useful quantities, with logarithms 81
24. General hydraulic table for channels with segmental cross sections for various depths on inverts, where (d) is the diameter in feet, giving values of area of cross section, wetted perimeter, and hydraulic mean depth 83
25. Pipe 3 ins. in diameter, giving values of A, R, and $\sqrt{R}$, for various depths on invert 84

PAGE

26—42. Pipes 4 ins., 5 ins., 6 ins., 7 ins., 8 ins., 9 ins., 10 ins., 11 ins., 12 ins., 15 ins., 18 ins., 21 ins., 24 ins., 27 ins., 30 ins., 33 ins., and for 36 ins. pipe, giving values of A, R, and $\sqrt{R}$, for various depths on invert ... 85–101

43. Values of A R and $\sqrt{R}$ for circular pipes, conduits and sewers, flowing full 102

44. Area and hydraulic mean depth of oval sewers (old form) 103

45. Area and hydraulic mean depth of oval sewers (new form) 104

46. V-shaped flume, right angled cross section 104

47. Values of (ζ) and (κ), Darcy and Bazin's formula 105

48. Open segmental channels. Values of (c) for various hydraulic radii between 0·1 and 1·0, Darcy and Bazin's formula 106

49. Values of $\frac{l}{n}$ for different degrees of roughness, varying from n = ·007 to ·05, Ganguillet and Kutter's formula 107

50. Values of S, $\sqrt{S}$ and $\left(a + \frac{m}{S}\right)$, for open and closed channels for various inclinations, Ganguillet and Kutter's formula 108–121

51. Value of (n) for different channels compiled from Kutter, Jackson, and Hering 122

52. Value of (n) for different surfaces exposed to the flow of water 123

53. Variations in value of (n), maximum and minimum 125

54. Variations in value of (n), average (Wollheim) 126

55. Values of $\sqrt{\frac{1}{S}}$ for various slopes 126

56. Velocity and Discharge calculated by Ganguillet and Kutter's formula, circular pipes, sewers and conduits, flowing full (n = ·013) 128–159

57. Velocity and Discharge, calculated by Ganguillet and Kutter's formula, egg-shaped sewers (old form), flowing two-thirds full (n = ·015) 160–169

58. Velocity and Discharge, egg-shaped sewers (old form), calculated by Flynn's modification of Kutter's formula, for various depths on the invert (n = ·013) 170–173

59. Square roots of a few quantities 174

60. Resistance to thrusting stress, stoneware drain-pipes 204

61. Stoneware pipes, dimensions of 205

62. Granite stoneware sanitary pipes, particulars of 206

63. Granitic stoneware pipes, Sykes' patent, particulars of 206

64. Concrete pipes, sizes in stock 209

65. Ames and Crosta pipe-joint, double seal, sizes made 217

66. ,, ,, pipe-joint, single seal and double seal, approximate depth of socket 218

67. Egg-shaped sewers (old form), sectional areas and cubic contents of brick-work per lineal yard 231

68. Concrete bed for stoneware pipes in soft ground, thickness of 236

69. Weight and thickness of cast-iron pipes suitable for drains 241

70. Weights of light, medium, and heavy cast-iron pipes manufactured by the Thames Bank Iron Company 242

71. Heavy cast-iron pipes for 300-feet working head 242

PAGE
72. Light cast-iron, tested to 300-feet working head 242
73. Approximate weight of socket pipes and connections for house drainage 246
74. Dimensions of socket connection in inches 247
75. Glass enamelled cast-iron drain pipes, sizes of 248
76. Glass enamelled cast-iron drain pipes, weights of 6-feet lengths 251
77. Capacity of flushing chambers 366
78. Subsoil drainage, number of rods in length and the net number of pipes required per acre 398
79. Lime and alumina, quantities used at the Glasgow Sewage Works .. 447
80. Richmond Main Sewerage Board Works, analysis of effluent 451
81. Analysis of the sewage effluent at Ashley Down Sewage Works, Sept., 1897 461
82. Analysis of effluent, Chorley Corporation Sewage Works 462
83. Massachusetts, average composition of the sewage used, parts per 100,000 466
84. Lowcock's summary of results of Massachusetts experiments 478
85. Lowcock's filter, Wolverhampton sewage, analysis of the effluent... ... 481
86. Summary of results obtained by Colonel Waring, at Newport, U.S.A. ... 489
87. Wolverhampton, Lowcock's filter, analysis of effluent 490
88. Dibdin and Garfield filters, mean results in parts per 100,000, with percentage purification 506
89. Septic tank process—Analysis of effluent 512
90. Results of the chemical analysis of the "effluent" from Colonel Ducat's Aërobic Cultivation Filter 515
91. Comparison between the crude sewage and the effluent from Colonel Ducat's Aërobic Cultivation Filter 515
92. The Scott-Moncrieff system—Analysis of result 528
93. Power available for Utilization at various Destructor Installations ... 544
94. Tests of power available with Worthington Pumps, Southampton ... 544
95. Safe maximum loads for various soils (Newman) 592
96. Value of ϕ for various earths 594
97. Compressive strength of concrete in tons per square foot 595
98. Transverse strength of concrete supported at end 596
99. Wind pressure and thin plates from experiments of Mr. Smeaton and Mr. Dines 596
100. Wind pressure in lbs. per square foot on chimneys of various heights ... 597
101. Wind pressure on solid bodies of various forms 597
102. Value for $\frac{a}{b}$ giving position of centre of wind pressure on inclined surfaces 598
103. Normal pressure on oblique plane height for various inclinations of roofs 598

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Wright Sutcliffe and Sons, Globe Sanitary Works, Halifax.

CORRIGENDA.

Page 31, *fig.* 24, *and paragraph at foot.*—The Interceptor here illustrated and described was first introduced by Mr. J. F. Bateman, C.E., F R.S., in the Manchester Waterworks.

Page 71, *paragraph at foot.*—The above correction also applies to the Separating Weir here referred to.

Page 237.—The title to fig. 126 should be "Manhole with Side Entrance."

Pages 450, 451.—"*Richmond Main Sewerage Board Works.*" Mr. William Fairley, A M.I.C.E., the Board's Engineer, informs me that they now have *eight* filters covering one and a-half acres at these Works; and that the average cost of chemicals is about 20*s*. per ton (November 8th, 1898).

SANITARY ENGINEERING.

INTRODUCTION.

If the human body is to be maintained in health and vigour, it is essential to dispose of all those matters eliminated from the animal system, whether in health or disease, as well as all other animal and vegetable refuse in the vicinity of inhabited buildings, as speedily as possible before decay begins, as in the early stages of putrefaction the matters evolved are highly injurious to health and dangerous to life.

This is more particularly the case wherever human beings congregate in any numbers, as in villages, and still more so in towns. History records many instances of the evil effects in all ages of large bodies of troops being encamped for any length of time, or repeatedly on the same spot.

The causes of zymotic disease are external to the human body, and each type is found to possess its own specific germ from which it is generated, and which must thus be introduced into the human system in order to produce the disease.

These germs appear to be world-wide in their range, though certain descriptions more particularly affect certain localities, and only await favourable conditions of environment to develop their latent dangerous characters.

There are three channels by which such poison can be introduced into the body, viz., by air, water, or food ; and it is therefore very necessary to guard all three from any possibility of contamination, notwithstanding the fact that a variable amount of such poison may be, and often is, taken with impunity ; this is due to the provision of nature which enables the human body to protect itself to some extent from the deleterious matter thus introduced, to throw it off from the system by those channels provided for the secretions and waste products, and if unsuccessful in so doing, it is due either to the existence of conditions in the body itself which defeat this action, or to the virulence of the poison to be combated.

The germ may be very small in the first instance, but it is impossible to say how rapidly it may develop with a suitable environment.

Typhoid bacilli can be blown about in dust, and in this way get into milk or water and be directly swallowed.

Where soil is saturated with rain water, the bacilli perish, and however salubrious in other respects gravels and sands may be found, yet typhoid fever is more prevalent with such sites than where stiff and cold clays prevail. The latter are unfavourable to the bacilli, whereas they have a happy hunting-ground in loose sand and well-aërated gravels ; the action of strong winds upon the latter favours the growth of the microbes ; a high barometric pressure and temperature also favour the growth of the bacilli.

A heavy rainfall in summer has in many instances been found to lessen the amount of disease, not only in that season, but in the following winter, and this is apparently due to the rain interfering with the germination of the bacilli.

The site for habitations being chosen, for a variety of reasons the science of Sanitary Engineering is called in to prevent a condition of things arising which would be hostile to the health of the community, and to do this the surroundings as well as the subsoil must be kept pure and uncontaminated.

The ventilation, warming, and lighting of inhabited buildings, although important branches of sanitary engineering, are not touched on in this work.

Advance in Sanitary Science.—Very great strides have been made of recent years in sanitary science, due to the fact that serious outbreaks of zymotic disease at various times have necessitated careful investigation of their causes, the result being traced, as a rule, to inattention to sanitary principles, involving defects either in the system adopted, or in the apparatus employed.

Constant improvements are being effected, so that a great deal that found favour some few years ago would not be tolerated for a moment now that further light has been let in on the subject.

As the size of a community increases, so does the difficulty of getting rid of the refuse already referred to as dangerous to health, and this more especially applies to the liquid refuse which contains foul matter in suspension as well as in solution.

Dry animal and vegetable refuse may be collected in ash-bins and be carted away, but liquid matter requires more elaborate arrangements.

The liquid refuse, termed sewage, is defined by the Rivers Pollution Commissioners to be "water mixed with any refuse that may affect public health," and according to another definition, "By sewage is meant the liquid contents of a sewer."

CHAPTER I.

COLLECTION AND REMOVAL.

THE reasons that have already been given in the Introduction for the prompt removal of the sewage and other deleterious refuse of any community point to the necessity for the adoption of an adequate system for the purpose. The following are the systems at present in use :—

I.—SEWERAGE (WATER CARRIAGE).

(*a*) **The Combined System.**—By which all sewage, surface water, subsoil water, and manufacturer's refuse are carried into the same sewer.

(*b*) **Modification Excluding Subsoil Water.**—The next system is a modification of the preceding, in so far as that the subsoil water is carefully excluded from the sewers.

(*c*) **Absolutely Separate System.**—The absolutely separate system involves the use of three sets of drains, one for foul water or sewage, one for surface water, and another for subsoil water.

(*d*) **Partially Separate System.**—Then we have the partially separate system, which is a combination of the "combined" and "absolutely separate" systems.

II.—PNEUMATIC.

(*e*) **Shone's Hydro-Pneumatic Ejector System.**—The Shone system of sewerage is applicable wherever the sewage of a town or district requires to be lifted, and may be described as a system of distributed stations for the lifting of sewage.

(*f*) **The Liernur System.**—This system of sewerage was introduced by Captain Liernur, a Dutch engineer. It is in operation in several Continental towns, amongst which may be mentioned Amsterdam, Prague, and St. Petersburg.

It consists in removing the fæcal matter from water-closets, and the foul water from kitchen sinks, by pneumatic agency.

The air-pumps and collecting reservoirs are situated in a central station. The town is divided into districts, with a central air-tight iron tank, to which the water-closets are connected with air-tight pipes; these tanks are in their turn connected with the central station.

There are special arrangements for regulating the removal of the excretal refuse from the different districts. There is a constant indraught in the closet pans. As little water as possible is used on this system, or allowed to enter the drains, so as not to dilute the sewage.

The liquid manure thus collected is mixed with from 1 to 1½ per cent. of sulphuric acid, and transferred to a steam concentrator, which is heated to about 100° Centigrade, and the sludge is then brought to the consistency of syrup.

In some instances the farmers take it, but there is not much demand for it, and in Holland it is conveyed by barges to the suburbs, where it is mixed with ashes and made into semi-dry manure.

The working expenses amount to about 4*s.* 10*d.* per head per annum.

III.—Interception.

Where a dry method is in force for the collection of the excrementitious matter, it is called the system of interception or conservancy. There are a great variety of appliances for the purpose, such as earth closets, pails, and tubs.

Under this head are also included middens and cesspits, as they have to be periodically emptied.

(*g*) **Cesspits.**—In places where no main sewers exist, and where there is no river or other conduit into which the drainage of a house may be led, it may be necessary to have recourse to a cesspit. It is, of course, a very objectionable method.

Such pits should be sufficiently large to contain all the drainage for several months, but it will be well to remove it frequently by pumping; there is usually some garden ground to which the sewage can be applied.

The best and least offensive system for emptying a cesspit is the pneumatic system.

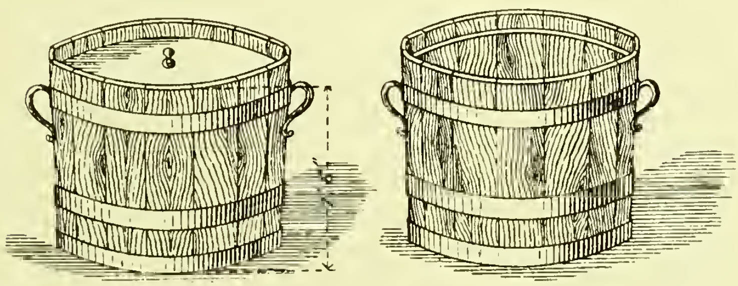
The pneumatic system acts as follows:—A large air-tight cylinder on wheels, or what answers equally well, a series of air-tight barrels, connected together by tubes about three inches diameter, placed on a cart, is brought as near to the cesspit as is convenient. A tube of about the same diameter is led from the stop-cock on the cylinder, or nearest barrel, to the cesspit. The air is then exhausted in the barrels or cylinder, either by means of an air-pump, or injected steam, which, on condensation, forms a vacuum. The stop-cock is then opened, and the contents of the cesspit are drawn through the tube by atmospheric pressure into the cylinder or barrels.

Cesspits should be placed as far as possible from any dwelling, and cut off by a disconnecting trap, and properly ventilated with inlet and outlet shafts provided with suitable cowls, such as those made by Messrs. Boyle & Son. In such a position cowls would be most useful, as there would be no alternating current of air to deal with.

Means of deodorization should be provided when the pit is emptied.

Sulphate of iron would appear well adapted for use with cesspits.

(*h*) **Soakpits.**—If made in porous soils so that the liquid soaks away, they are called *soakpits;* they are dangerous to neighbouring wells, and lead to saturation of the soil. In some cases, when formed in chalk,



WOODEN PAILS.

FIG. 1.—Elevation with cover. FIG. 2.—Elevation without cover.

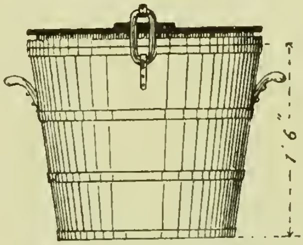
gravel, or other porous soil, with a low level of subsoil water, and the water supply is not obtained from wells, no injurious results may follow.

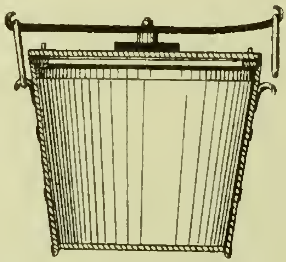
(*i*) **Middens** are shallow receptacles in the ground, formed of masonry; their capacity should not be greater than 40 cubic feet, and they should be lined on the inside with cement to prevent soakage. The floor level of the interior should be slightly above that of the adjoining ground. They require periodical cleaning at least every three months, and are, of course, most objectionable from a sanitary point of view.

(*j*) **Pails and Tubs.**—The pail and tub system is simply an improvement on middens.

Some of the forms of pails adopted are shown in Figs. 1 to 4.

The pails used at Rochdale are made from petroleum casks cut in two, re-staved and hooped, and provided with air-tight covers, as Figs. 3 and 4. When finished they are 18 inches in diameter at the top, 15 inches at the bottom, and about 16 inches deep. Special carts are employed for collecting the pails, with compartments to receive them ; the pails





PAIL WITH AIR-TIGHT SPRING COVER.

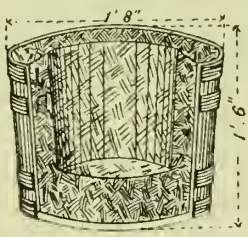
FIG. 3.—Elevation. FIG. 4.—Section.

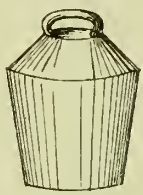
are at the same time replaced by clean ones. Specially coloured pails are supplied to houses where cases of infectious disease exist.

Each pail lasts about two years.

The pails may also be made of galvanized iron or steel.

On the Goux principle, used at Halifax, the pails have an absorbent lining of dry refuse, which is shaped by means of a mould for the purpose (Figs. 5 and 6). The pails are relined at the works after emptying.





PAIL WITH ABSORBENT LINING FOR "GOUX" SYSTEM.

FIG. 5.—Section. FIG. 6.—Mould.

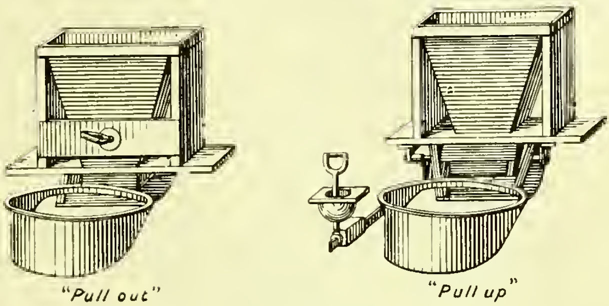
(*k*) **Earth Closets.**—Earth closets, properly so-called, are, for the most part, either Moule's or Taylor's. They are made to act by pulling or raising a handle, or else automatically, by which means a discharge of dry earth or ashes is intended to take place each time they are used (Figs. 7 and 8).

Fig. 9 is the automatic arrangement, and the ordinary pail used.

An improved form of pail is sometimes used with these closets, as shown in Fig. 10.

The buckets have to be emptied when full, and replaced by clean ones.

A special description of earth closet, patented by Mr. John D. Garrett, C.E., is employed at the house called "Woodroyd," near the Bigsweir Great Western Railway Station, Gloucestershire. The closets are arranged above each other with a recess or open shaft behind them, down which the contents of the containers can be tipped from the inside of the house into a bin on the ground floor, which also receives all solid



Figs. 7 and 8.—Moule's Earth Closets.

refuse. The earth for the closets is raised by means of a bag and pulley up the same shaft. According to Mr. Garrett the bin need only be cleared out and deodorized once a month. A special barrow for filling into the scavenger's cart is provided, to be run up temporary ways, and then tipped in without allowing any dust to escape. The cart is also a special feature of the system, the middle compartment being arranged so as to tip the contents in bulk into a special railway truck for removal into the country. The sides of the cart are intended to carry the bags of dry earth for the closets.

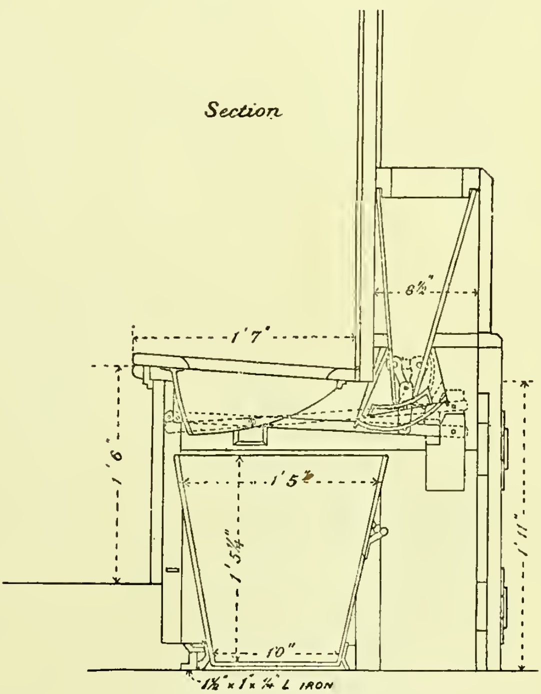


Fig. 9.—Section of Moule's Automatic Earth Closet.

Temporary Latrines.—In latrines for the use of troops and for temporary purposes, the earth is very often kept in boxes on the floor of the various compartments, a scoop being provided with which to supply the earth ; but the application of dry earth in this manner is, as might be expected, too often neglected, so that it is not a very perfect arrangement. In connection with it sheds must be provided to store the earth, and also hot places to dry the latter when required.

Plate I. gives the necessary details for a temporary latrine of this description. A permanent latrine on this system might be made with seats in two rows, and back to back, with a passage between for the removal of the pails. An arrangement for drying earth on a small scale is shown in Fig. 11.

Cost of Removal of Excrement.—The removal of the excrement thus collected by the different methods of interception entails considerable labour and careful supervision, especially if carried out on a large scale.

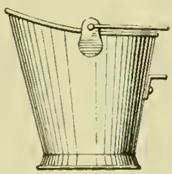


Fig. 10.—Pail for Earth Closets.

Rochdale is completely drained, but with the exception of 750 water-closets to the better houses the removal of excreta, etc., is on the conservancy system. At Rochdale for 1896–97 the actual cost for the collection of night-soil and ashes (which are kept separate) was 12*s.* 2*d.* per closet, and for night-soil only would be about 6*s.* 3*d.*, whilst at Stone, Staffordshire, the cost was 8*s.* 4*d.* per pail; it is generally considered to be a most expensive system, and one which does not give resultant benefits proportional to the excessive cost in carrying it out in a proper and efficient manner.

Water-carriage is rapidly displacing the conservancy system, and in consequence of the difficulties involved, towns like Glasgow, Birmingham, Nottingham, Leicester, etc., have decided to abandon the pail system altogether in favour of water-carriage pure and simple, and even in Manchester, where the pail-closet replaced the privy and middens which obtained there until 1871, water-closets are being introduced. The pail system is only being fully retained in Hull, Rochdale, Warrington, and Darwen.

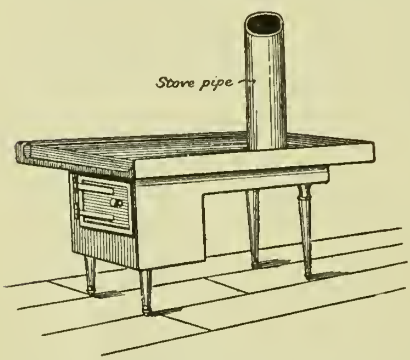
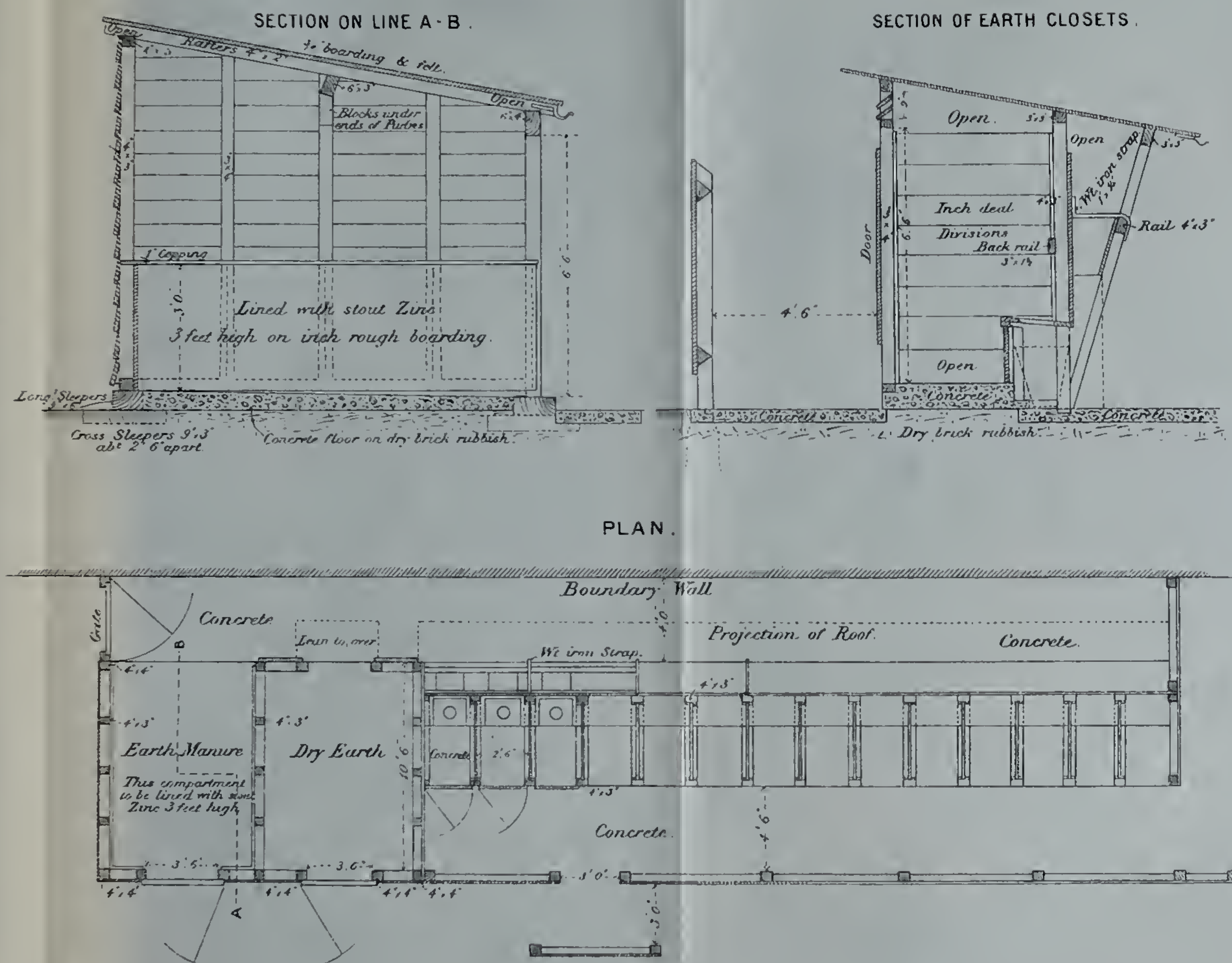


Fig. 11.—Apparatus for drying earth on a small scale.

According to Mr. H. Alfred Roechling, C.E., observations have lately been made in Leicester, Newcastle-upon-Tyne, and Birmingham as to the bearing of tubs and water-closets upon the prevalence and spread of typhoid fever, the

PLATE I.

TEMPORARY EARTH CLOSETS AND SHED.



J. Akerman, Photo lith. London

comparison being constituted between different parts of the town where tubs and sewers exist.

In Leicester the typhoid cases were more numerous in those districts where the fæcal matters were collected in tubs than in the sewered portions of the town ; and during an epidemic in 1894, in Navigation Street the number of typhoid-infected houses was five times as many as in the case of those provided with water-closets.

"Dr. H. E. Armstrong mentions that in 1894 enteric fever was twice as prevalent in Newcastle-upon-Tyne in households on the pail-closet system as in households on the water-closet system."

Similar experiences are reported by the medical officer for Birmingham, who stated that in 1894 the typhoid incidence was 1½ times as great in houses with pails as in houses with water-closets, and that, as regards second cases, one occurred in every 14 houses with pails, but only in every 22 houses with water-closets.

Comparison of Systems.—The pneumatic system (Liernur) requires drains to convey waste and storm-water, in addition to those used for the removal of the sewage. Expensive works, consisting of district reservoirs and central collecting stations, with machinery, etc., are also necessitated. Both systems (II. and III.) involve the use of drains of some description to carry off the bulk of the liquid refuse, so that sewerage or water-carriage by gravitation is evidently the most economical method for the collection and removal of sewage from large centres of population, and it is certainly the most effective.

Mr. G. J. C. Broom, M.I.C.E., F.G.S., states there are about twenty-four towns in England which have adopted "Interception" to any considerable extent ; of these fifteen are situated for the most part in Lancashire, and have a large working-class population. The system has been adopted with the object of avoiding a large expenditure which would be necessitated by the adoption of water-carriage with a largely increased water supply, and the difficulties hitherto experienced in the decision as to the scheme for sewage disposal to be adopted.

At Rochdale "difficulties were experienced in the disposal of the excreta to farmers in a crude state, and it was therefore necessary that something should be done to decrease its bulk, and at the same time to provide a manure which would be free from rubbish, more easily carried to and distributed upon the land, and which could be placed upon the market as a saleable commodity. This brought about the manufacture of the excreta into a dry manure, which at the present time has a ready sale at £6 per ton. The present (1895) number of pail-closets in the borough of Rochdale is about 18,147, old privies and middens 138, and water-closets 650, for a population of 72,325." There are very great difficulties in carrying out the system of Interception in a satisfactory manner, as it requires a great deal of supervision, the collection at all hours is objectionable, and it is impossible at all times to prevent the emission of effluvia from the vans and pails, thus creating a nuisance.

The pail system can thus only be regarded as an intermediate system between the midden and water-carriage, and as a means by which the excreta can be removed with less nuisance and more easily and frequently than in the case of middens; there is less risk also of polluting the soil and air.

It is claimed to be "well adapted to the wants of sparsely populated districts, and especially villages whose water supply is taken from wells, and where the excreta would be utilized on the spot as a manure; and also in towns where an adequate supply of water can only be obtained at excessive cost.

As an intermediate system it affords time for corporations to consider and experiment on the best method of disposing of the sewage of their town under the varied circumstances of the case.

CHAPTER II.

SEWERAGE.

Choice of System.—It is necessary, before preparing a design for the sewerage of any locality, to decide which of the water-carriage systems already mentioned is to be adopted.

The "absolutely separate" system is undoubtedly the most perfect when carried out in its entirety, the great advantage being that the number of traps required to prevent the escape of dangerous gases from the foul-water drains is reduced to a minimum; and, of course, no sewer-gas can escape at the gratings for surface water; thus the dangerous area is materially reduced, and may, to a great extent, be isolated. The size of the sewers may also be more easily adapted to the quantity of sewage they will have to convey, and greater facilities are afforded for their regular supervision and cleansing, the tendency to the deposit and formation of foul gases being at the same time minimized. The foul water obtained by this system, owing to the exclusion of the surface water, is uniform in composition, and much reduced in quantity, therefore its purification and utilization are less difficult.

The disadvantages of the absolutely separate system are that two sets of pipes (one for sewage and one for surface water) are required, and might lead to mistakes being made by workmen in connecting new drains to the wrong set of pipes, and also that the surface water from yards and streets is often very foul, particularly when a storm succeeds a period of drought, unless the yards and streets are constantly cleansed and well scavenged.

Some authorities consider that the separate system is less expensive than the combined, as although two sets of drains are involved, yet those provided for surface water need not be so elaborate as those for sewage; *e.g.*, old culverts, watercourses, etc., may be utilized, and expensive traps and ventilating apparatus of large proportions are not required.

Mr. W. Santo Crimp, in his book "Sewage Disposal Works," states that in suburban districts, true economy may thus be observed by constructing small sewers for the sewage, and for a small proportion of the rainfall only, old culverts, as above mentioned, and badly-constructed sewers being utilized for the disposal of rain-water.

In 1885 the separate system was adopted at Wimbledon on his recommendation, in order to prevent the flooding of the sewers which took place during heavy rainfalls, in consequence of the rapid increase of the population. This was completed in 1886, and since that date all new streets "have been provided with two sewers," the street-water going off with that from the fronts of new houses into the rain-water sewer, "whilst the sewage, with the roof-water and washings from back-yards, goes into the sewer proper."

At Southampton, Mr. W. B. G. Bennett, C.E., the Borough Engineer, in accordance with his scheme* for the revision of the drainage of the eastern and western districts of Southampton, is making new drains for the sewerage, and will retain the old sewers, for the most part, for rainfall drainage only. The reason for this is "that many of the present sewers are very large, and lie at much too low a level compared with the tide; consequently, at high water it has been found difficult to discharge them." It is therefore imperative, in order "to prevent a recurrence of the constant flooding of the basements in the lower districts at times of heavy rainfall, and also to provide at the same time an efficient system for ventilating the sewers and preventing the formation of sewer-gas," to lay "a new set of sewers in such a manner as will permit of discharge at any state of the tide."

It is not, however, always convenient to carry out the system completely, as it might necessitate a long length of pipe being laid to carry off the surface water of a small courtyard in an out-of-the-way corner, where the existence of a foul-water trap might be considered as unlikely to be prejudicial to health.

The "partially separate" system thus recommends itself, if judiciously applied, and the principles, on which the absolutely separate system are based, are at the same time carefully kept in view. Care must be taken in the arrangements for the sites of the gullies that slops and foul water shall not be thrown into gratings intended for surface water only.

Drains and drainage may, therefore, be considered under the following separate heads:—

(*a*) Sewerage, including foul water from w.c.'s, urinals, sinks, wash-houses, etc.

(*b*) Surface drainage, comprising water from roofs, roads, pavements, etc.

(*c*) Subsoil drainage.

The following definitions of the terms used in various works dealing with the subject are useful:—

* For a full description of the new scheme of main sewerage at Southampton, see pages 576—583, *post*.

SEWERS-RAMPS IN.

PLATE II.

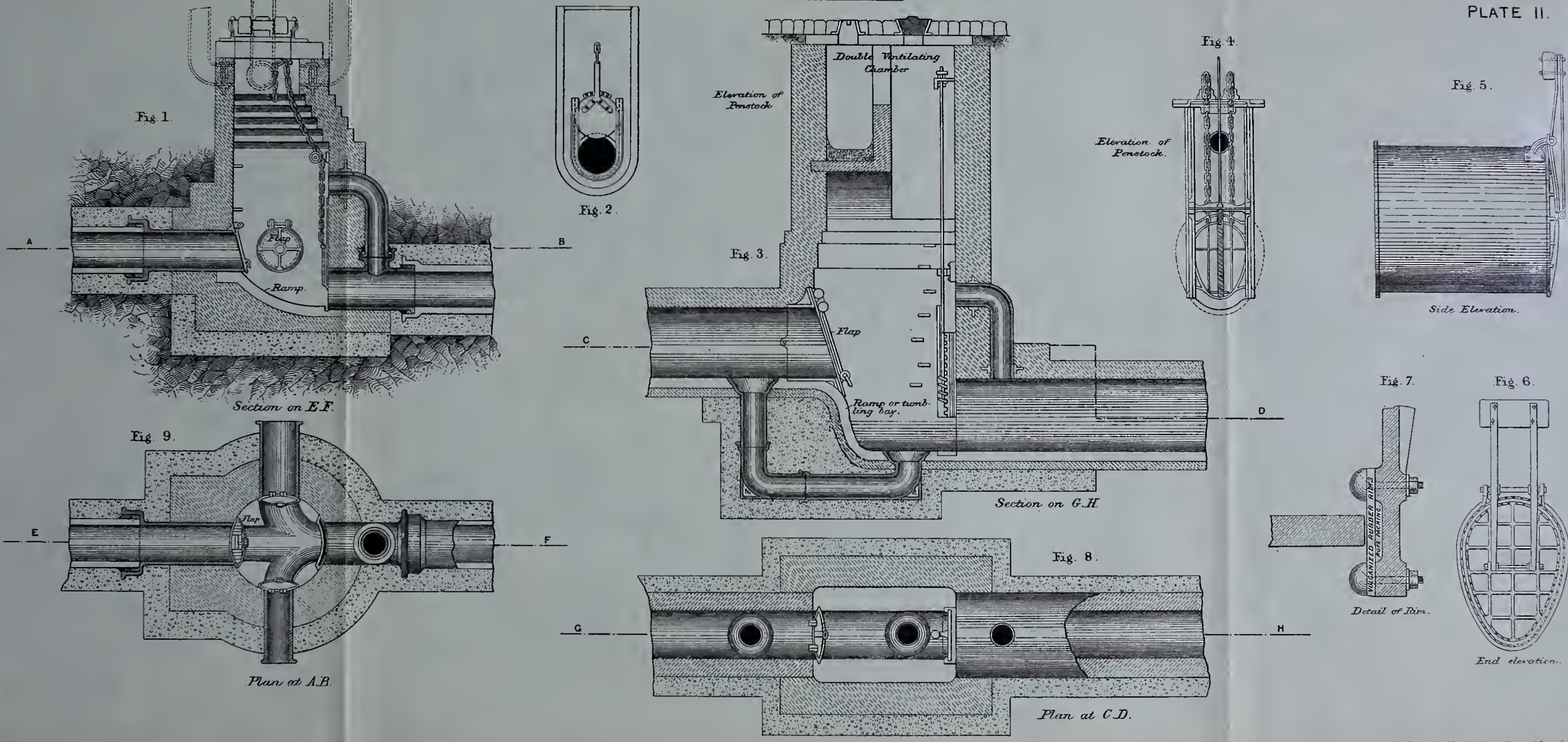


Photo-Lithographed & Printed by James Akerman, 6 Queen Square W.C.

Definitions.—Drains or sewers may be defined as conduits for carrying off liquids of any kind in any position, but the term is understood to refer specially to underground pipes of metal, stoneware, brickwork, or concrete ; the liquid consists of sewage, and subsoil or other water.

Drains and Sewers.—In order to define these properly it is necessary to refer to the law on the subject. On referring to the 11 & 12 Vict. c. 112, the Act of 1848 to consolidate and continue the Metropolitan Commissions of Sewers, sect. 147, and the 11 & 12 Vict. c. 63, the Public Health Act of 1848, sect. 2, we find that the word "drain" is in both cases defined as meaning and including any drain of and used for the drainage of one building only, or premises within the same curtilage, and made merely for the purpose of communicating with a cesspool or other receptacle for drainage, or with a sewer into which the drainage of two or more buildings or premises occupied by different persons is conveyed ; the word "sewer" meaning and including sewers of every description except drains to which the word "drain" interpreted as aforesaid applies. This definition was re-enacted in the Metropolis Local Management Act of 1855, sect. 250, and in the Public Health Act of 1875, sect. 4, and was last interpreted and confirmed in the case of *Travis* v. *Utley* in 1893.

Section 23 of the Public Health Act, 1875, empowers an authority to require the owner or occupier of any house to drain such house into a sewer where such sewer is not more than 100 feet from the site of such house in accordance with the directions of the authority.

The statutes applying to London provide:—By sect. 73 of 18 & 19 Vict. c. 120, that any house may be required to drain to a sewer, if there be a sewer within 100 feet of the house (this distance is extended to 200 feet by sect. 66 of 25 & 26 Vict. c. 102), in a manner to satisfy the vestry or district board, and if the owner neglect during twenty-eight days after notice to commence to comply, the vestry or board may execute the work and recover the cost from the owner.

Section 75 makes it unlawful to erect any house unless its lowest floor can be satisfactorily drained into a sewer.

Section 76 forbids the excavation of any foundations of any new house or the making of any drain until seven days' notice shall have been given to the vestry or board, so that the vestry or board may make their order as to the level of the lowest floor of the house, or as to the making of such a drain.

Drains are generally constructed and maintained by private individuals, and sewers by public authorities, to carry the drainage of more than one building, but a difficulty in a distinct definition arises in the case of certain intermediate portions which in many instances unite the drains to the sewer : on the one hand, when carrying the drainage of more than one building they might be considered as "sewers," and on the other, lying as they do for the most part within private premises for the greater portion of their length, and having been constructed in the first place by private individuals, they might be classed as "drains." This leads us to the consideration of "combined drains." Now, as regards a "combined drain," we understand it generally to mean a pipe or culvert of small calibre in continuation of the drains of two or more houses to the sewer. Section 74 of the Act already referred to empowers a vestry or board to order that a group or block of houses be drained by a combined operation if it appear to the vestry or board that such group or block of houses may be drained and improved more economically or advantageously in combination than separately.

The Amending Act of 1890 recognises the existence of "combined drains," and by section 19 fixes the liability for their maintenance on the owners; but that section only takes effect "Where two or more houses belonging to different owners are connected by a single drain to the sewer," so that where several houses belonging to one owner are drained together, such "drain" is a "sewer," and must be maintained by the local authority.

In the Metropolis Local Management Act, 1855, sect. 250, it is provided that "the word *drain* . . . shall also include any drain for draining any group or block of houses by a combined operation under the order of any vestry or district board." This definition being subsequently extended by the Act of 1862, sect. 112, to include "any drain for draining a group or block of houses by a combined operation, laid or constructed before the 1st day of January, 1856, pursuant to the order or direction or with the sanction or approval of the Metropolitan Commissioners of Sewers."

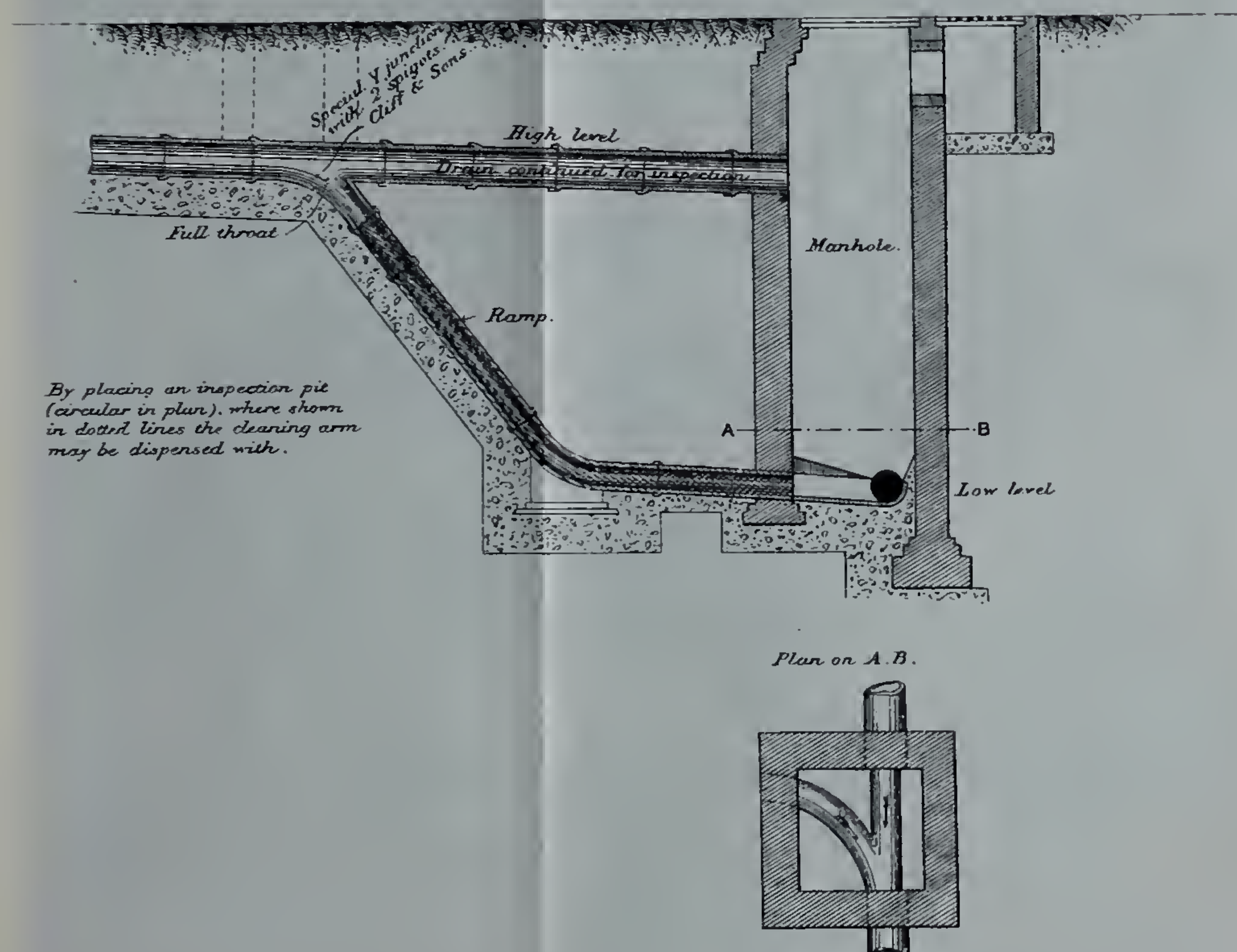
This only refers to the Metropolis, and as regards the rest of the country "combined drainage" is not sanctioned at all. The condition of the law on the subject thus leaves the question, as to what is a "drain" and what is a "sewer," open to many conflicting opinions; a list of Cases and Decisions is given by Mr. Robert Godfrey, A.M.I.C.E., in a paper communicated by him in "Proceedings of the Incorporated Association of Municipal and County Engineers," vol. xxi., 1894–95.

General Principles.—Having selected the system on which the drainage of any particular locality is to be carried out, the plans should be carefully prepared, so as to secure uniformity throughout.

The position to which the sewage is to be delivered by the sewers requires careful arrangement, especially where pumping has to be resorted to, so as to minimize the lift, and the consequent cost; in the latter case the minimum gradients consistent with efficiency would be given to the drains.

PLATE III.

JUNCTION BETWEEN HIGH AND LOW LEVEL DRAINS.



J Akerman Photolith London

Intercepting sewers at different levels may also be arranged so as to reduce the cost as far as possible.

A town which is completely and properly sewered will have a system of underground sewage-conduits, formed with even lines and gradients, true in cross-sectional form, and capable of transmitting sewage at rates of from one mile per hour, to six or seven miles per hour by flushing. If the town stands upon a site such as Brighton, Bristol, or Liverpool, care should be taken to so plan and execute the main sewers that the area shall be sub-divided by intercepting sewers, or by "*ramps*" and double ventilation, as in Fig. 3, Plate II. (page 12), so as to prevent the lower parts from being flooded with the downward flow of storm-water sewage, and the upper parts of the town being injured by the upward flow of sewage gases. This system of sub-dividing and intercepting the sewage, and specially ventilating the main sewers, will be found to be of the utmost importance; as if sewers are not so dealt with, suburban houses, however superior in construction and accommodation, may be poisoned by the transmission of sewer gases from the lower parts of the town to the higher parts.

If the sewers have steep gradients, and the flow of sewage is unbroken, a velocity in the sewage is produced, which is liable to be very injurious in its wearing action, and during heavy rains it acquires such a velocity as not only to wear out the invert and blow the joints, but also to burst the sewers. Stoneware pipes, under such circumstances, should be bedded in concrete and it would be preferable to use iron pipes where steep gradients are required. It is necessary in such sewers to provide means for regulating the flow. In arranging the levels for the various portions of the sewers, it must be remembered that they are all converging to one point, consequently their intersections must be carefully considered.

Sewers and drains at junctions and curves should have extra fall to compensate for friction.

Levels.—In order to connect a high level pipe sewer with one at a low level, a *ramp*, such as that shown in Plate III., is generally employed to prevent the evils of a direct fall. The exit at the high level should be made with a very full throat, to check the tendency of storm-water to leap the opening, and run straight on through the inspection arm, which is only provided for inspection and clearing purposes. The necessity for an inspection arm may be entirely obviated by the introduction of an inspection pit, as shown dotted in Plate III. Plate IV. shows the syphon drops designed on the principle of Sir R. Rawlinson for breaking rapid falls, as adopted at Rochdale.

Where culverts are used, a similar system should be adopted, and in that case, iron pipes of smaller sectional area than that of the upper sewer should be employed for forming the ramp.

Types of sewer outlets for use on the sea coast are given in Plates V. and VI. ; the latter is only applicable where ample fall is available.

Depth of Sewers, etc.—The depth of the sewers and drains below ground must be regulated so as to enable them to drain the basements of the houses.

Manholes.—There should, if possible, be manholes at all junctions and bends. A manhole fitted with a 21-inch sluice, as used on the Metropolitan sewerage works, is shown in Plate VII. (page 18), and the details of the manhole used at Rochdale, in connection with the syphon drops for breaking the velocity of sewage on steep gradients, is shown in Plate VIII. (page 18).

Straight Lines between Manholes.—Unless there is some practical difficulty in the way, each sewer should be laid in straight lines, and with even gradients between man and junction-pits (*vide* Plate IX., page 20).

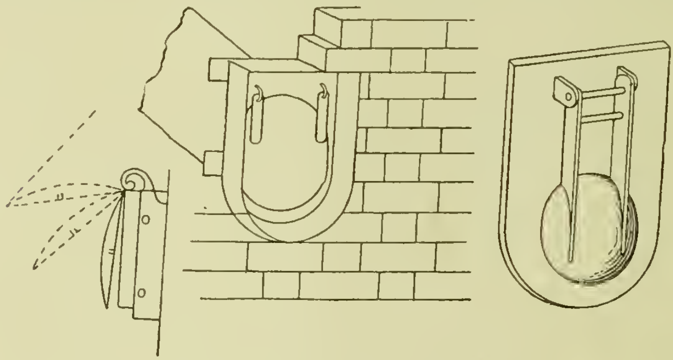


Fig. 12.—Tankard Valve for Sewer.

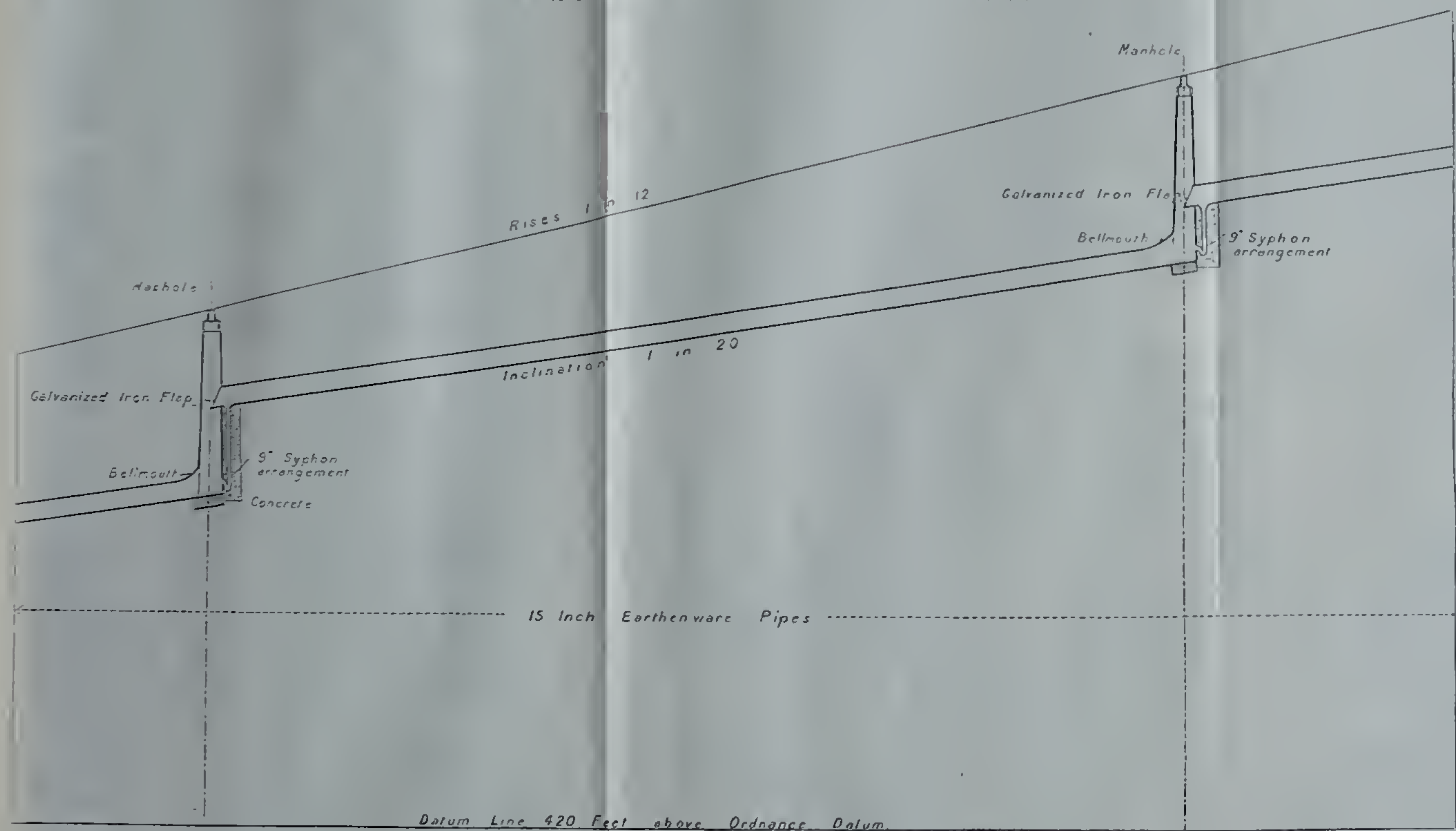
Valves.—When the outfall of a sewer is subject to a rise of tide, it may be protected by a self-closing flap, or tankard valve, to prevent the sewage from being forced back into the system. All the working parts of a tankard valve should be bushed with gun-metal, to prevent the valve from sticking (see Fig. 12 ; also Figs. 5, 6, and 7, Plate II., page 12).

A properly constructed tide valve should be entirely self-acting, and should regulate the discharge of the sewers at the outfall of which it is fixed.

Storage Tank.—When sewers deliver in such a position as to be liable to be covered by a rise of water, the pressure being insufficient to overcome the obstruction, or when it would be objectionable to discharge the sewage with a rising tide, the lower end of the sewer must be made large enough to store the sewage whilst the outlet is closed (*vide* Plate X., page 20). An overflow outlet should also be provided for flood-water.

Plate IV.

METHOD OF SEWERING STEEP STREETS. Example as carried out at Rochdale.



Horizontal Scale: 30 feet to an inch. Vertical Scale: 10 feet to an inch.

To face page 14.

Inverted Syphons.—Where it is found necessary that a sewer should cross a river, stream, or valley in its passage towards the outfall, and it is inconvenient to bridge the stream at the level at which the sewer must be constructed, inverted syphons are generally adopted.

To effect this the pipes, which should be of strong wrought iron, are laid, in the case of rivers and streams, in three ways, viz., by means of barges or lighters, by forming cofferdams, or by tunnelling the bed of the channel.

For this purpose it is customary to provide manholes on both banks of the channel to be crossed, which also serve as convenient places for the removal of any obstruction that may occur.

There is a considerable difference of opinion as to the form inverted syphons should take, and the method to be adopted in their construction.

In some cases pipes are made to follow the sectional outline of the river or channel, by which arrangement there are usually two sloping lengths and one flat length of pipe. If such a syphon be used for crude sewage, and the volume is intermittent and uncertain, there is a liability of chokage, owing to heavy matter carried by the sewage being deposited in the flat length.

It is usual, therefore, during construction to pass a chain through the pipes and secure the ends in the manholes on the adjoining banks, so that it may be drawn backwards and forwards, and thus stir up and set in motion any sedimentary substances that may have been deposited.

Syphons should, therefore, be laid in duplicate, with penstock chambers at each end, so that the sumps can be cleared of débris. When constructing long inverted syphons, ventilation must be provided at the descending leg of the syphon, otherwise air will accumulate there, and will probably interfere very seriously with its discharging power. This may be effected by carrying pipes from the bend up to such a level that, even when the flow is interrupted, they will not overflow.

It is usual to relieve such syphons from having to carry storm water, by providing suitable overflows into the river.

Pumping or Lifting.—Owing to local circumstances, such as the low-lying portions of a town in relation to its outfall, it may be necessary to lift, or raise, the sewage by artificial means in order to dispose of it. This may be done either by pumping or by the use of Shone's hydro-pneumatic ejectors (Figs. 13 and 14, page 18), which are placed at various points in the districts of a town, and are worked by compressed air from one central station, whereby the whole drainage area is divided into a number of compact districts, each with its separate outfall and discharging station, the discharge from all the stations converging into one common main leading to the ultimate common outfall.

The advantages claimed for such a system are as follows, comprising :—

(1.) "The interception of the bulk of the sewage at higher levels, and consequent saving of power as compared with a single pumping station, in which the whole bulk has to flow down to the lowest point merely to be pumped back again, the fall to the pumping station being so much absolute waste of power.

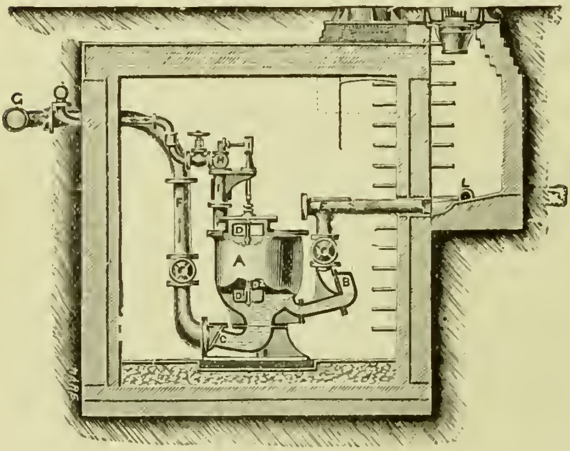


Fig. 13.—Section.

(2.) "The obtaining of short, good, and self-cleansing gradients from the houses to the district outfalls or ejector stations, with small sewer-pipes in which there is no room for the accumulation of sewage gas.

(3.) "The entire severance of each district from the main sewer and the rest of the drainage area. Thus, in the event of any epidemic disease breaking out in one district it cannot be conveyed by the sewers into healthy districts, as is often the case when the whole area is connected by a network of drains leading to one common outfall.

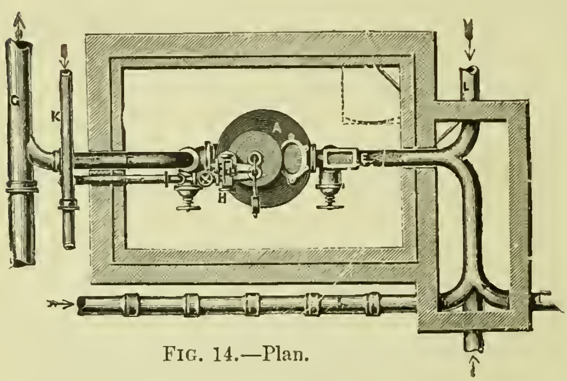


Fig. 14.—Plan.

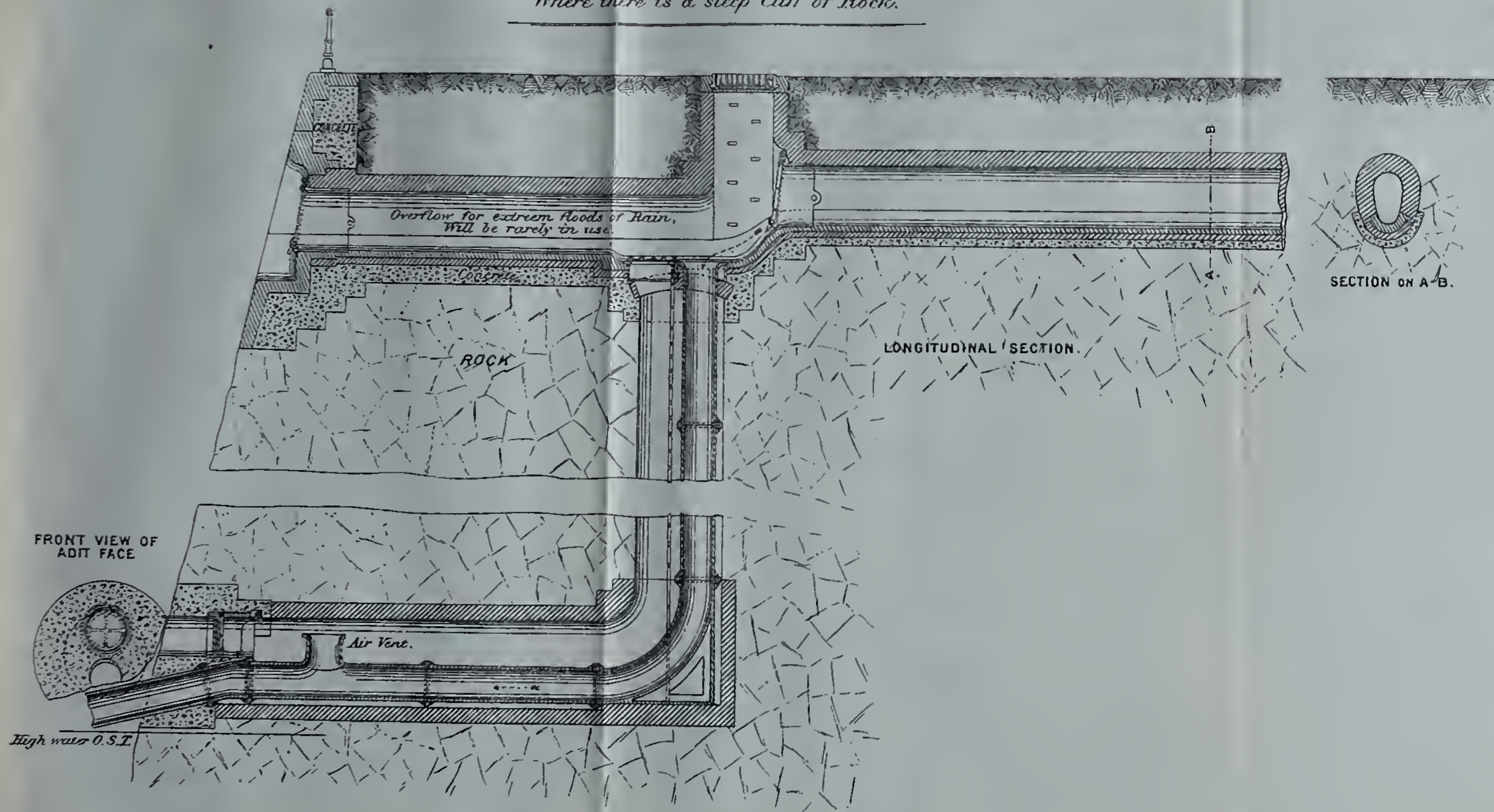
Figs. 13, 14.—Shone's Pneumatic Ejector in brick chamber.

(4.) "The avoidance of deep cuttings and of large sewers, whereby great economy is effected in first cost.

(5.) "The ready extension of the system in proportion as the

SEWER OUTLET ON SEA COAST OR TIDAL RIVER. PLATE VI.

Where there is a steep Cliff of Rock.

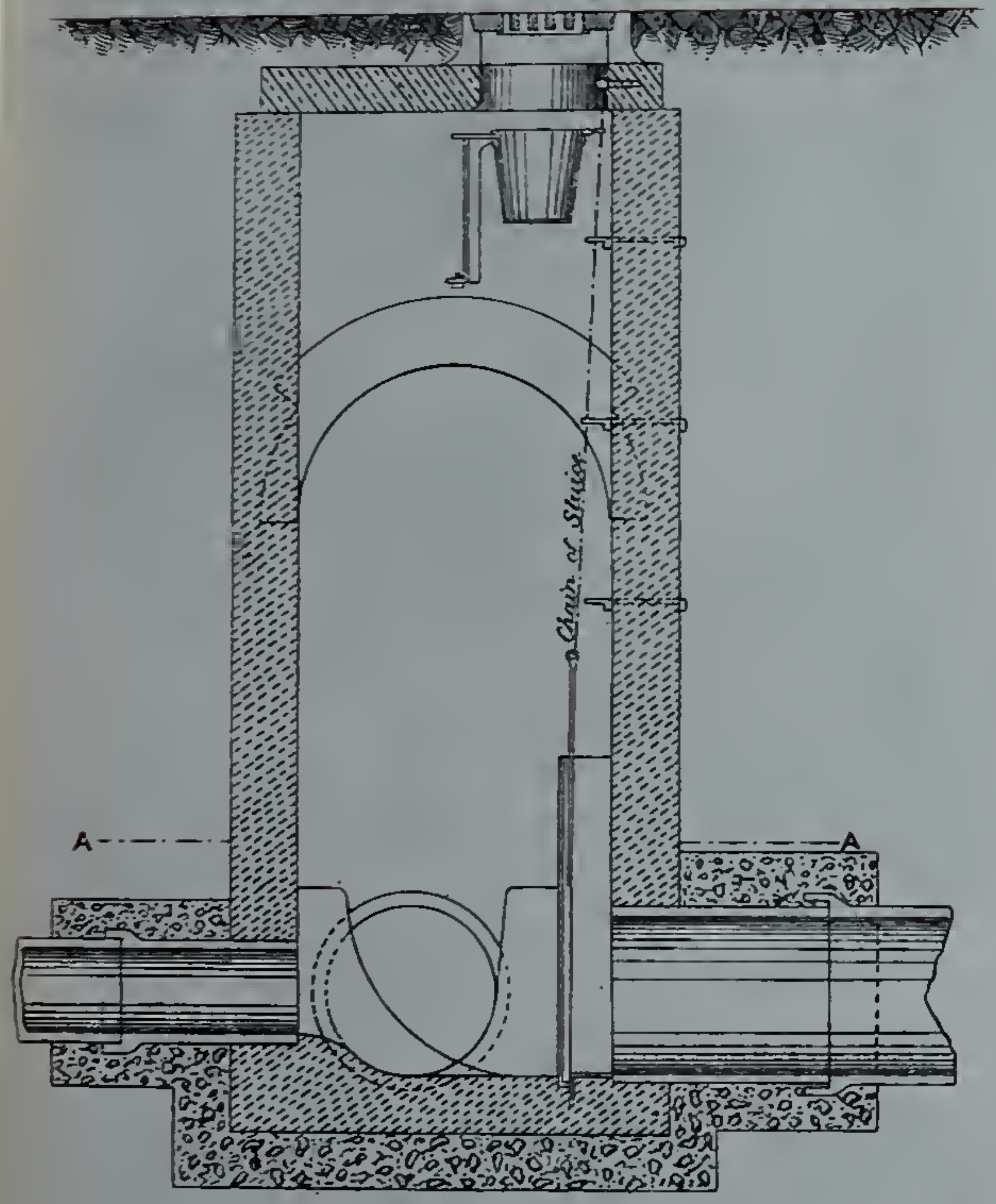


J. Akerman, Photo lith London

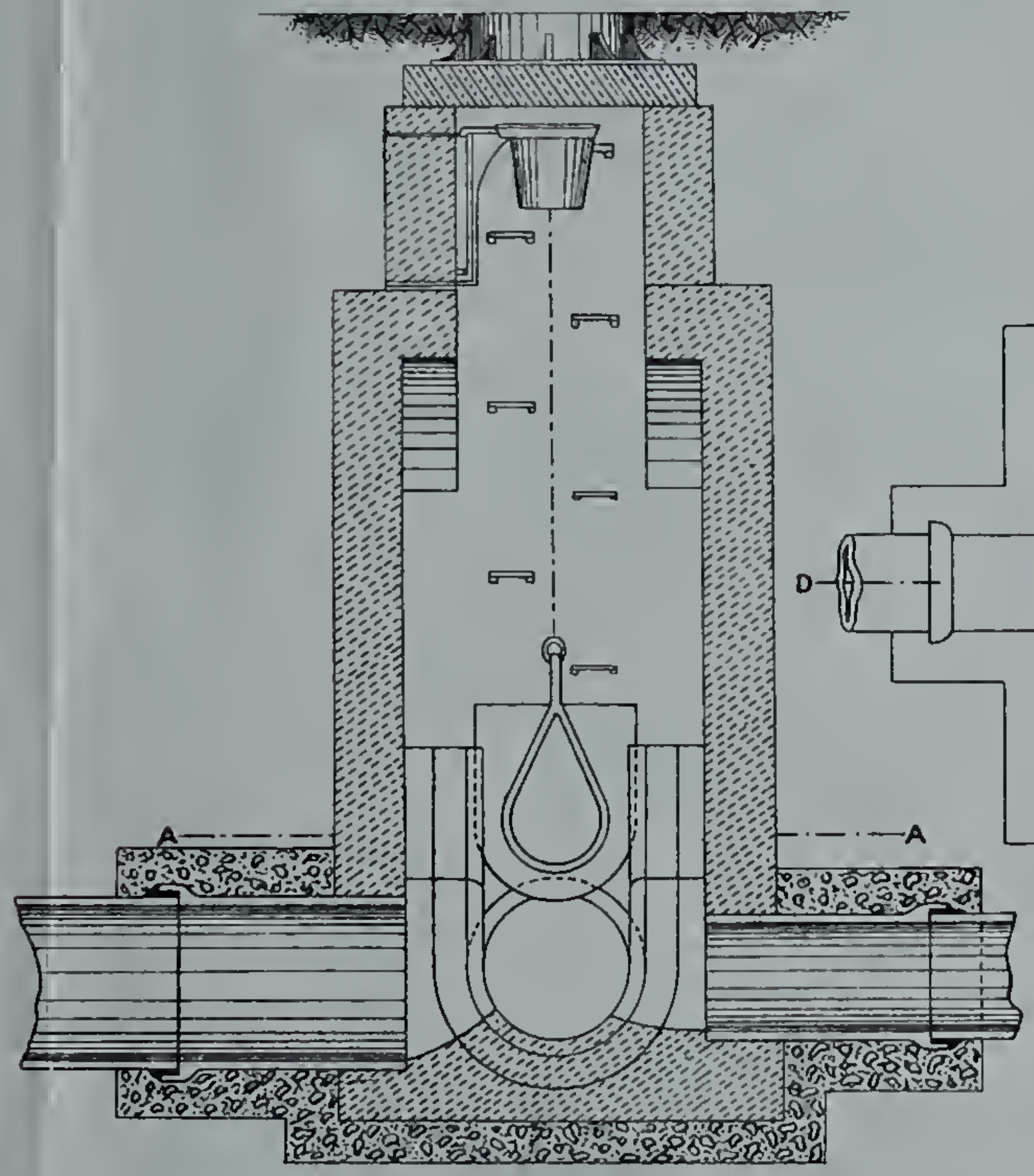
MANHOLE WITH 21" SLUICE AS USED ON THE METROPOLITAN SEWERAGE WORKS.

PLATE VII.

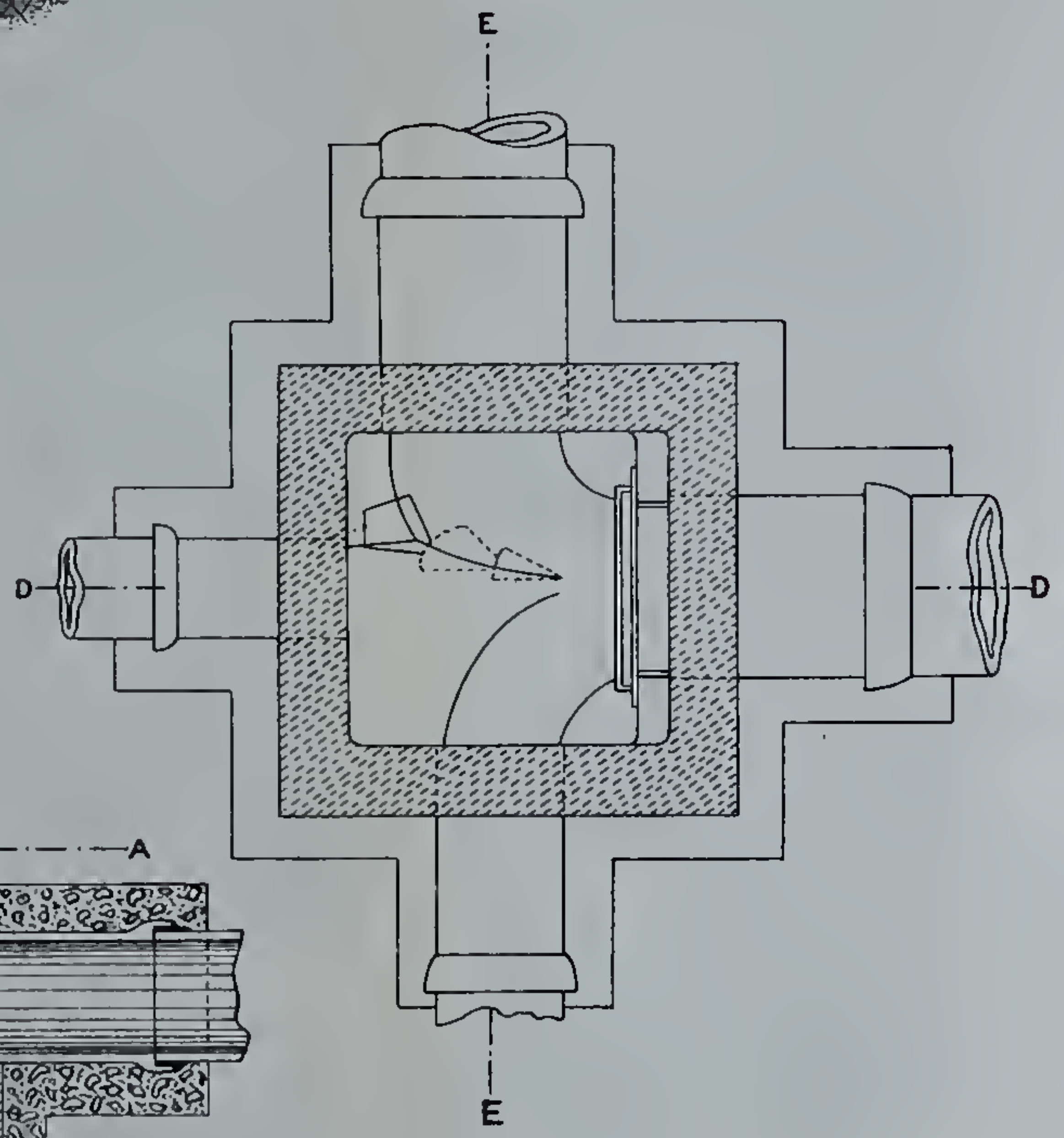
SECTION ON D-D.



SECTION ON E-E.



PLAN AT A-A.



PLAN AT TOP.

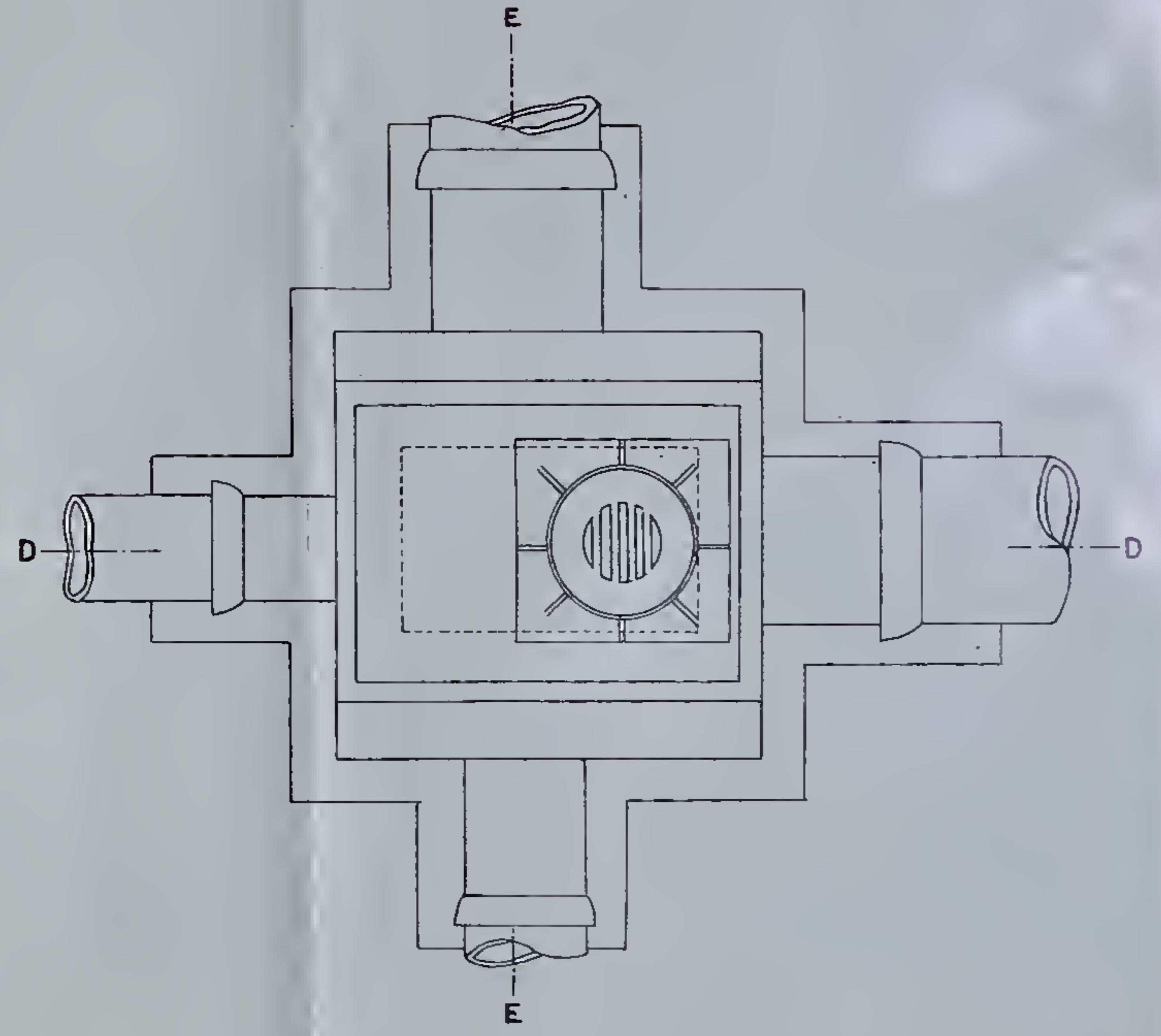


Photo-Lithographed & Printed by James Akerman, 6, Queen Square W.C.

population and occupied area increases, thus avoiding the heavy outlay in providing for probable future requirements, and relieving the ratepayers of the present day of the heavy burden of providing prematurely for the wants of a possible future population.

"But the disadvantage of distributed sewage pumping stations of the ordinary kind would obviously be in the multiplication of establishment

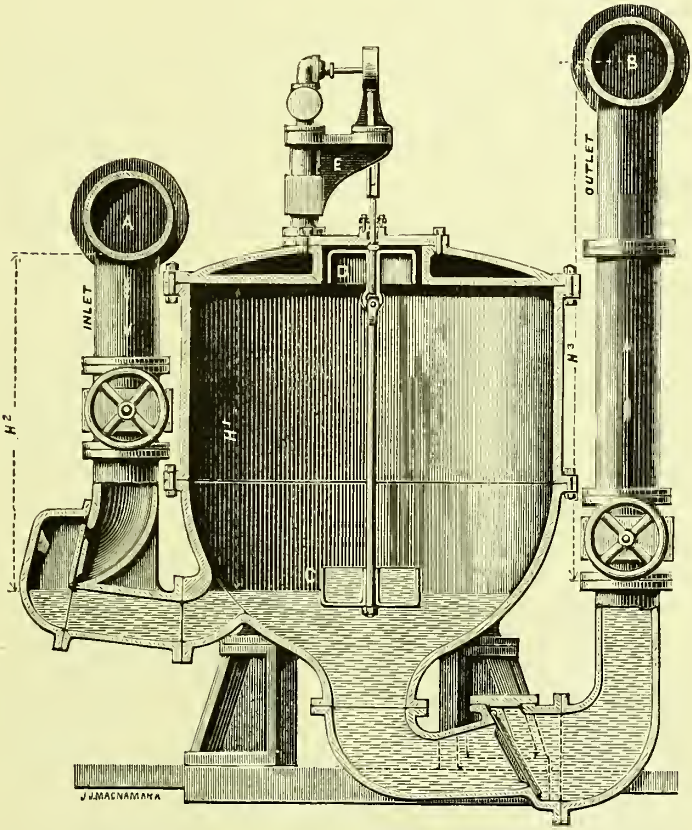


FIG. 15.—Section of Shone's Pneumatic Ejector.

expenses by the maintenance of a separate staff of superintendents, assistants, and workmen at each such station. To overcome this difficulty, Mr. Shone devised his patent sewage ejector, which can be placed under the street and worked by compressed air. Any number of these can be worked from one central air-compressing station. The ejector is simply a large iron pot or vessel placed under the roadway, into which the sewage of the district flows until it is full, when compressed air is automatically admitted on top of the sewage, ejecting it in a few seconds into the main outfall sewer—the process repeating itself automatically as long as there is sewage to flow. It is the invention of this apparatus which has rendered the distributed station system practically attainable.

"Fig. 15 gives a sectional view of a Shone pneumatic ejector of ordinary construction, suitable for raising water, sewage, sludge, chemicals, and hot fluids of all kinds. Ejectors are made of any size or shape convenient for the special circumstances for which they are required. For sewage, sludge, pail contents, preference is given to those having the lower portion of hemispherical shape.

"The motive power employed is compressed air, and the action of the apparatus is as follows:—

"The sewage gravitates from the sewers through the inlet pipe A into the ejector, and gradually rises therein until it reaches the underside of the bell D. The air at atmospheric pressure inside this bell is then enclosed, and the sewage continuing to rise outside and above the rim of the bell compresses the enclosed air sufficiently to lift the bell, spindle, etc., which opens the compressed air admission valve E. The compressed air thus automatically admitted into the ejector presses on the surface of the sewage, driving the whole of the contents before it through the bell-mouthed opening at the bottom, and through the outlet pipe B into the iron sewage rising main or high level gravitating sewer, as the case may be. The sewage can only escape from the ejector by the outlet pipe, as the instant the air pressure is admitted on to the surface of the fluid the valve on the inlet pipe A falls on its seat and prevents the fluid escaping in that direction. The fluid passes out of the ejector until its level therein reaches the cup C, and still continuing to lower, leaves the cup full until the weight of the liquid in the portion of cup thus exposed and unsupported by the surrounding water is sufficient to pull down the bell and spindle, thereby reversing the compressed air admission valve, which first cuts off the supply of compressed air to the ejector and then allows the air within the ejector to exhaust down to atmospheric pressure. The outlet valve then falls on its seat, retaining the liquid in the sewage rising main; the sewage then flows into the ejector through the inlet once more, driving the free air before it through the air-valve as the sewage rises, and so the action goes on as long as there is sewage to flow.

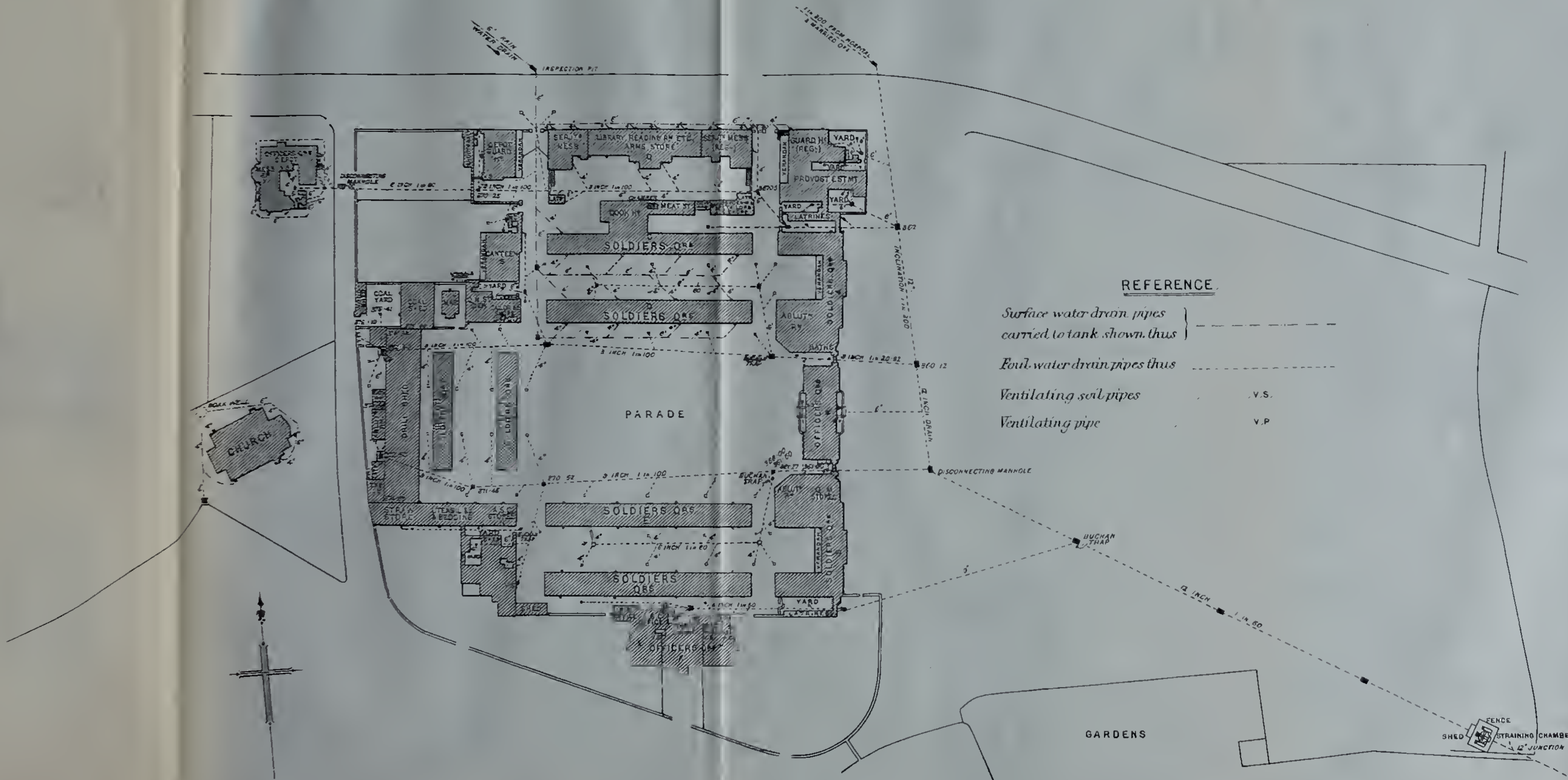
"The position of the cup and bell-floats is so adjusted that the compressed air is not admitted to the ejector until it is full of sewage, and the air is not allowed to exhaust until the ejector is emptied down to the discharge level.

"The compressed air for actuating the ejector is produced at some

WARLEY BARRACKS DRAINAGE.

Scale $\frac{1}{500}$.

PLATE IX.

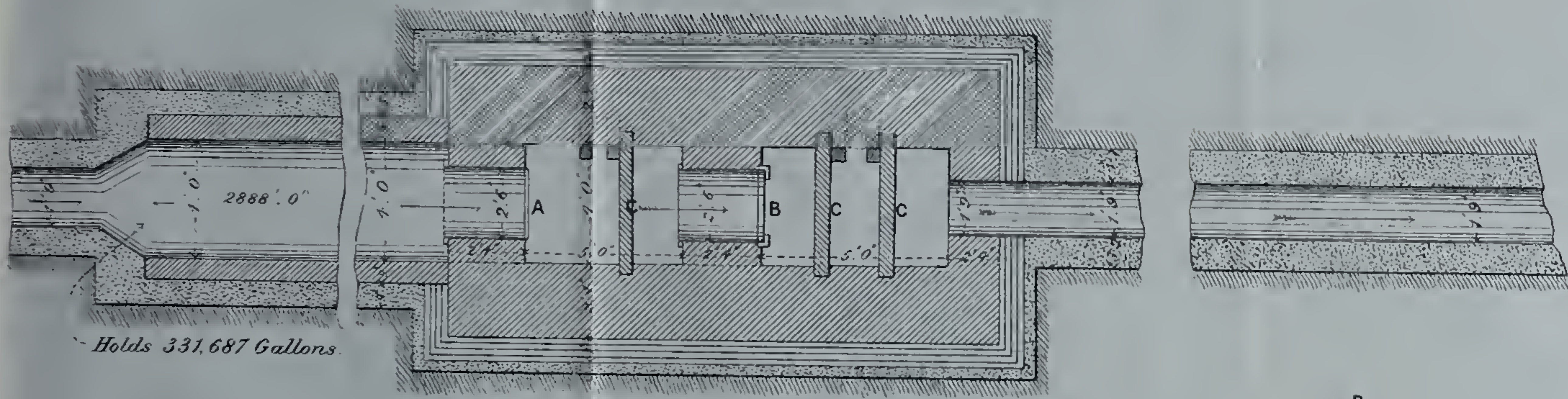


J. Akerman, Lith. 6, Queen Square, London W.C.

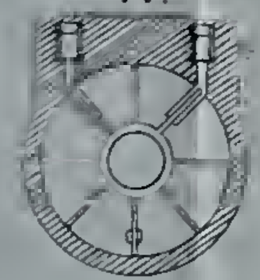
SEWER OUTFALL.

PLATE X.

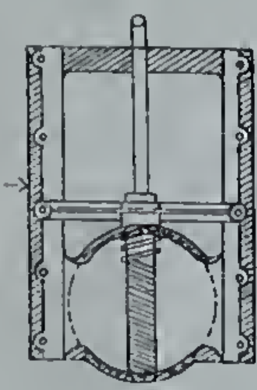
PLAN OF PENSTOCK CHAMBER.



A.



B.



Reference.

A – *is a tankard valve.*
B – *is a penstock.*
C – *are grooves in brickwork for forming a temporary dam.*

central station, and conveyed in cast or wrought-iron pipes laid under the streets to the several ejector stations."

The advantages of this apparatus, it is stated, may be summed up as follows :—

(1.) "The working parts are reduced to a minimum, and those of a kind not likely to get out of order.

(2.) "The parts into which the sewage enters contain no tooled surfaces, such as are unavoidable in pumps, and get rapidly destroyed by the action of the sewage sludge and grit from road detritus, etc. In the ejector there is nothing but the hard skin of the castings, coated with Dr. Angus Smith's composition, upon which the sewage can produce no detrimental effect.

(3.) "The friction of a pump piston and other working parts is avoided, the compressed air itself acting direct upon the fluid, without the intervention of any machinery, and forming an almost absolutely frictionless and perfect *air piston*, past which there can be no slip or leakage whatever.

(4.) "The cup and bell-float arrangement is one that cannot possibly get out of order, as an ordinary rising and falling float would be liable to do.

(5.) "The *only* tooled parts are those in connection with the small automatic air-valve, which makes only one movement, of two or three inches, for each discharge of the ejector of from 50 to 1,000 gallons (according to the size of the ejector), and is only in contact with the compressed air, and out of reach of the sewage.

(6.) "The sewage inlet and outlet valves are so arranged as to give a passage-way of the full area of the pipe, allowing a free passage to all the solids that the pipe itself can carry.

(7.) "The outlet is from the bottom of the ejector, so that the whole of the sewage, including solids, sludge, grit, and everything brought down the sewer, is discharged out of the ejector.

(8.) "For these reasons, no screening or straining of the sewage is necessary, as is the case with pumps, and the great nuisance caused by the cleaning of pump gratings and sump wells is avoided.

(9.) "The sudden rush of the whole contents of the ejector, when the discharge is into a main gravitating sewer, forms a most effective flush.

(10.) "The ejector forms an absolute severance of the house drains of each district from the main sewer.

"The use of compressed air in mining, tunnelling, and for driving domestic and other motors, as in the case of the Paris Compressed Air Power Company, furnishes abundant proof that with properly jointed and correctly proportioned pipes, the losses by leakage and friction, through even miles of pipes, is insignificant."

The ejectors are in successful use at Warrington for the transmission of pail contents from central depôts in the town, through 2½ miles of cast-iron main, to the works at Longford, saving the Corporation over £1,200 per annum in cartage alone; and at Southampton for transmission of sludge through a length of 1,500 yards of 4-inch cast-iron main. They are also in use for the same purpose at the Barking and Crossness Outfalls, London, at Plymouth, Shirley, Freemantle, Rochdale, Eastbourne, Southampton, Warrington, Staines, Ipswich, Norwich, Felixstowe, and many other places both in this country and abroad.

In towns where the solid refuse—ashes from private house bins, etc.—is destroyed by fire in specially constructed furnaces, the resulting heat may be utilized for generating steam to work air compressors, and the site of the refuse destructors may be used for the compressing station, as has been done at Southampton and other places; or the compressors may be placed at the gas or waterworks, or other site where steam or water power is available.

Shone's hydro-pneumatic ejectors have also been applied at Rangoon, and the following is a description of the system as there carried out (Plate XI.):—

"A gravitation system of sewage *per se* for a perfectly flat and tide-locked city like Rangoon was naturally found impracticable, and could not, under any circumstances, be recommended on sanitary grounds. After considerable inquiry by the municipality, it was decided, with the approval of the Government of India, to adopt the Shone system as being the only known system by which the city could be properly drained on sound sanitary principles.

"The works were commenced in February, 1888, and completed by March, 1890.

"The city proper is divided into 22 sub-sections, or ejector districts, and within each of these districts is placed, in as convenient and suitable a position as possible, an ejector station, in which are placed two ejectors, each of 200 gallons capacity; one ejector in each station being capable of doing the maximum work, the other being in reserve in case of accident.

"All gravitating sewers converging and discharging to the several ejectors are of six inches diameter, cast-iron spigot and socket connections, and are laid throughout with steep gradients, none being flatter than 1 in 200; the total length of gravitating sewers being about 22 miles.

"The junctions for connection to the houses are five inches diameter, and have been carried in all cases above the water level in the subsoil.

"**Night Soil Depôts and Flushing Tanks.**—For the purpose of temporarily disposing of the excreta from the houses not yet connected

RANGOON SEWERAGE ON THE SHONE HYDRO-PNEUMATIC SYSTEM.

Plan of the City of Rangoon showing Sewage and Compressed Air Mains, Ejector Stations, Air Compressing Station, etc.

Lithographed & Printed by James Akerman, 6, Queen Square, W.C.

with the gravitating sewers, 130 night soil depôts have been erected and connected with the sewers in the back drainage spaces, to which depôts the excreta is carried in ordinary pails by the conservancy, and there discharged into a large trough, from whence it flows into the sewers and gravitates to the ejector stations.

"At the head of each length of gravitating sewer is placed a 200-gallon flushing tank, regulated to discharge automatically once or twice a day, or as often as experience shows it to be necessary, to keep the sewers perfectly clean and free from deposit.

"The sewage is discharged to the outfall at a level of three feet below the lowest tide through cast-iron sewage mains of various sizes, commencing at six inches diameter at No. 1 ejector station, and gradually increasing in size until they are finally 21 inches diameter from No. 20 ejector station to the outfall.

"The total length of sewage rising main is nearly six miles.

"**The Supplementary High-pressure Water Supply** forms a portion of the combined scheme carried out in Rangoon. The water gravitates from the Royal Lake into twelve of Shone's 500-gallon ejectors, from whence it is ejected by pneumatic pressure of 27 lbs. per square inch into the 27-inch water main, thus giving an additional head of 62 feet to the water delivered in the city.

"The whole of the sewage and water ejectors are worked by compressed air, produced at the compressing station, situated in Dalhousie Street, nearly opposite the New Government Offices. The compressing machinery consists of—

"Three complete sets of triple expansion steam engines, each engine having three air compressing cylinders 16 inches diameter, 24 inches stroke. The steam cylinders of each engine are of the following dimensions:—

High-pressure cylinder	...	12 in. diameter,	24 in. stroke.
Middle ,, ,,	...	$16\frac{1}{2}$,,	24 ,,
Low ,, ,,	...	$21\frac{1}{2}$,,	24 ,,

and are arranged in front of the compressing cylinders, so that each steam cylinder drives a compressing cylinder direct.

"Each engine is able to work up to 150 indicated horse-power.

"Five Lancashire steam boilers, each 22 feet 6 inches long, 6 feet 6 inches diameter, with two internal flues 2 feet 6 inches diameter, fitted with three Galloway tubes in each boiler, and stand a working pressure of 150 lbs. per square inch.

"Two air receivers, 24 feet long by 8 feet diameter.

"Two Atkinson's feed water heaters.

"Two donkey feed pumps.

"The cast-iron air mains for sewage and water ejectors commence at 10 inches at the compressing station, and are ultimately reduced to three inches diameter, with a total length of about six miles."

Sewage Lifting Apparatus.—In 1878 M. Liernur introduced his somewhat complicated vacuum system for the transmission and collection of sewage. Mr. Shone followed with his special machinery for the application of compressed air for the same purpose. In the Liernur suction drew the sewage into a cylinder from which it was liberated. In Mr. Shone's apparatus pressure forces the sewage from a receptacle. In both automatic valves bring about the desired operations, and both require engine power and pumps. As a means of distributing power they are convenient if not economical. It frequently happens, however, that a district having a small volume of low level to raise, has also, in its higher levels, the power necessary to do this work. The sewage lift invented by Mr. Adams is intended for such positions.

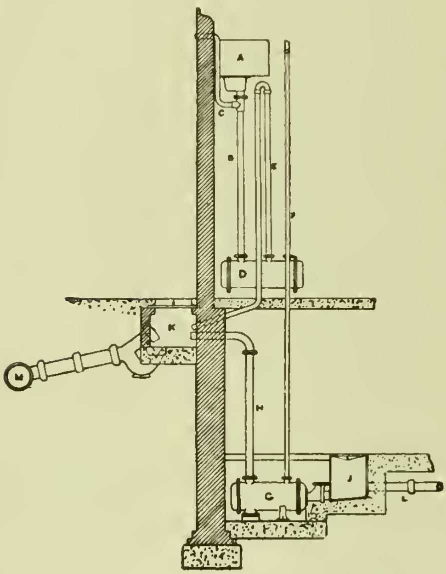


Fig. 16.—Adams' Automatic Sewage Lift.

The apparatus is absolutely automatic, *i.e.*, no engine, or pumps, or attendance are required. The sewage lift is designed as an accessory to, rather than the dominating principle of an entire scheme. Thus in practice, it is desirable that all the sewage which can be brought by gravity to its outfall should be thus carried, and that only that quantity which is created at too low a level to gravitate should be lifted. There is no doubt that to avoid the cost of construction and maintenance of pumping plant, the temptation is strong to lay sewers at non-self-cleansing grades, where (could these low levels be disregarded) good gradients are obtainable ; in such a case the value of the sewage lift is apparent. The following is a description of the apparatus :—

Adams' Patent Automatic Sewage Lift.—Fig. 16 shows a simple adaptation of the sewage lift. Here the extension of a growing district necessitated the provision of a sewer, that at M not being sufficiently deep. The sewer L has been laid, terminating at the chamber shown. Its contents are raised to M in the following manner :—An automatic flush tank A supported upon a cast-iron column is supplied from the Water Co.'s mains, and discharges when full to the air cylinder beneath it. The air contained therein is displaced by the incoming liquid being sent through the air pipe F to the forcing cylinder G below. Sewage from L is admitted to, but cannot return from the latter cylinder, a plain flap valve being placed at its entry. The height of column from A to D is in excess of that of the outgo pipe on rising main H. Air is thus transferred from D to G under a "head" in excess of that due to the resistance on rising main, and as the flush tank discharges to D, so will the contents of G be discharged to the sewer, until the cylinder D being full of liquid, an excess in the flush tank passing over a plain syphon pipe placed within the column, will bring about syphonic action, and the contents of D will be drawn off by this syphon, and delivered to (in this instance) the large flushing chamber below.

The supply to the flush tank above is controlled by a ball valve, which, rising or falling with the sewage, entirely shuts off the supply when there is no sewage to lift, and *vice versâ*.

It will be apparent that, provided this preponderance of power over work to be done is available, the relative positions of parts is immaterial.

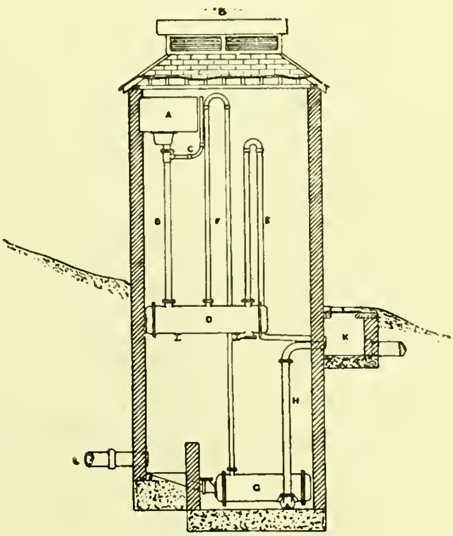


Fig. 17.—Adams' Automatic Sewage Lift.

Fig. 17 shows a very similar lift, where in lieu of the column, the tanks and cylinders are placed within a building. No intermediate flushing chamber is used in this case, the contents of D being discharged direct to the sewer.

Fig. 18 is a drawing of a small installation as used for raising sewage from conveniences which are placed in basements or at too low a level to gravitate direct to the sewer. The apparatus is very similar to that last described, but an inspection box fitted with air-tight cover is used. In dealing with institutions or office blocks, the flush tank and air cylinder are ordinarily fixed at such a height that the water may, after use in the apparatus, discharge into a storage tank, from which it is distributed to the sanitary fixtures on the various floors, so that there is absolutely no cost beyond that of construction in such a case.

It is possible to put basements in this way to uses which would otherwise be entirely out of the question.

Figs. 19, 20, and 21 show an installation of the sewage lift where the

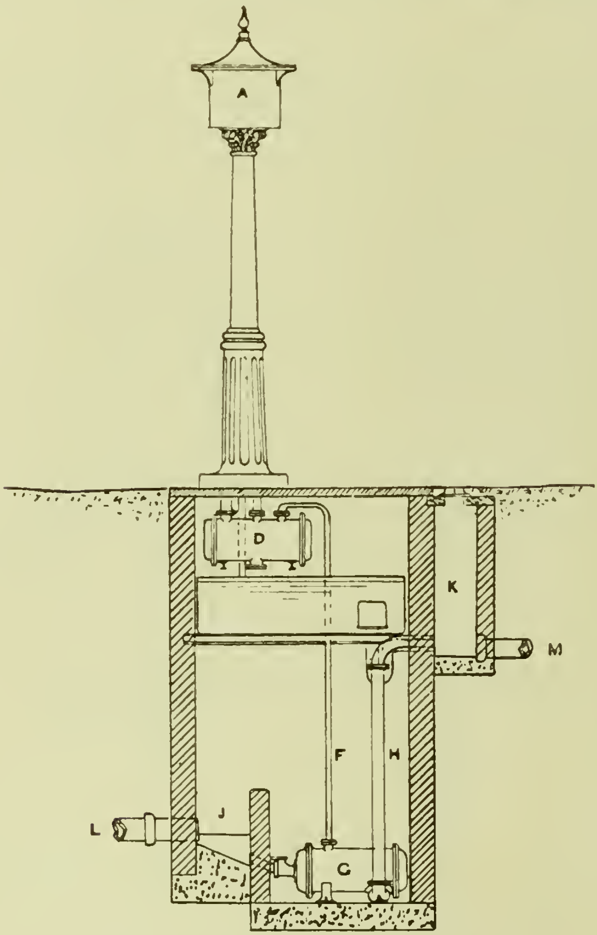


FIG. 18.—Installation of Adams' Sewage Lift for raising sewage from conveniences in basements, etc.

distance separating the various chambers is considerable : in this instance about a quarter of a mile of air pipe is used. In some cases a mile or more of air pipe separates the air and forcing cylinders.

The flushing chamber is built in brick. The supply to it is from the sewer N. The sewage passes a screen P on its way to the supply pipe, solids being carried off through O. The flushing chamber discharges its contents through the automatic syphon shown, to the pressure pipe B, and thus to air cylinder D. The latter is emptied by syphon pipe E ; at F is the air pipe conducting air to forcing cylinder G. The rising main H delivers into sewer above ; L is the low level sewer, and J the chamber through which it passes to cylinder G. The pressure pipe B has a vent pipe C attached thereto, through which air is drawn by the falling water and thus greater economy of liquid used effected.

In one case, at Wandsworth, owing to this air induction, one gallon falling is raising somewhat more than a gallon of sewage.

Draining by Deflection, Lynde's Principle.—The application of this principle to house drains is shown in Fig. 22, the ordinary method of draining being shown in Fig. 23. Mr. Lynde claims that by means of the "Loco" deflector bend and trap a high initial velocity is secured in the drain, thus entirely obviating the tendency for house drains as usually constructed to become choked. The sewage at some point (V) Fig. 23 down the drain acquires the velocity due to inclination of the pipe, whereas in the case of Fig. 22, it starts with a high initial velocity, due to the rapid discharge from the trap and the height of fall, on to a deflecting surface. The angle of incidence being equal to the angle of reflection, the velocity due to the fall is not checked, there is thus no sluggish flow of sewage after the water, for both the sewage and the water flow down the drain together.

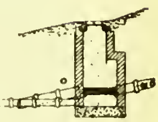


Fig. 21.

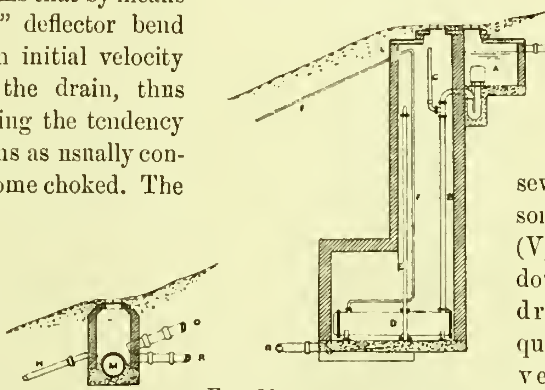


Fig. 20.

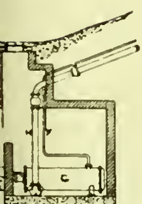


Fig. 19.

Figs. 19–21.—Installation of Adams' Sewage Lift.

Junctions not to be at Right Angles.—The house drains must not join the sewers directly at right angles ; in fact, such junctions should always be avoided.

If a manhole is used for the junction, the bottom can always be constructed so as to give the required curve in the direction of the flow of the current, as shown in Figs. 130-133 (page 239) and Plate VII. (page 18) ; by this means as little disturbance as possible is caused to the proper flow of the liquids along their respective channels.

Sewers of unequal sectional diameters should not join with level inverts, but the lesser, or tributary sewer, should have a fall into the main at least equal to the difference in the sectional diameter, or in other

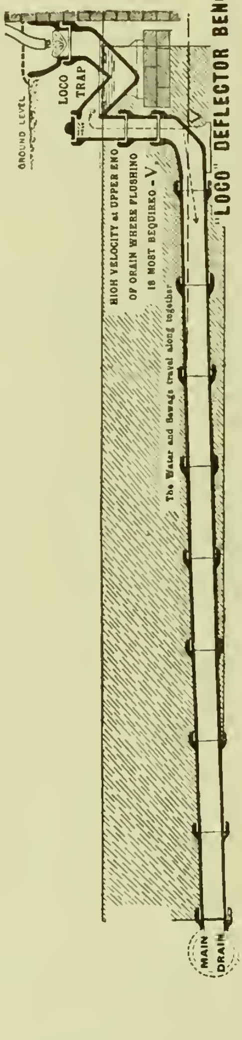


Fig. 22.—Draining by deflection.

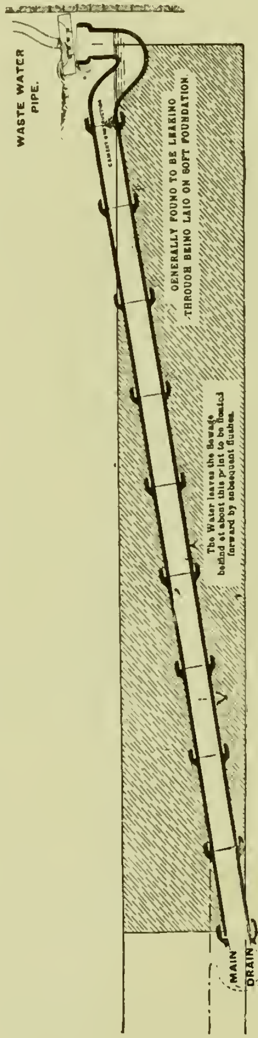


Fig. 23.—Ordinary method of draining.

words the soffits or covers of the sewers should be kept in the same line. Where pipe junctions are used, the socket should be slightly tilted, and the first length of pipe discharging into it be given extra fall, to check the tendency to backflow in the branch.

Cross Sections.—When the ordinary flow of sewage is sufficient to keep a sewer of circular section half full, that form is the best, being the strongest and cheapest.

When the flow is variable, and at times very small, the egg-shaped section should be adopted, as it gives greater depth for small flows than could be obtained with the circular section, the capacity for the maximum flow being the same in each case.

Thus, with a variable discharge, the hydraulic mean depth is a maximum for each section of liquid flowing through the sewer.

Area of.—The area of the cross section of sewers must be governed by the amount of sewage which they have to convey, their fall, and whether periodically flushed. Sewage, when fresh, causes no nuisance, but after about 24 hours, according to the weather, decomposition sets in, and it becomes putrefactive, producing deleterious gases. Their capacity should thus be sufficient to carry off in 24 hours the maximum quantity that may pass into them. In a town, the hourly flow of sewage varies considerably during the day in accordance with the domestic habits of the community; where baths are provided, there will be a corresponding discharge of soiled water into the sewer in the early morning; during the forenoon the water-closets and sinks will be contributing liquid of a more or less foul nature, whereas in the afternoon, the discharge will be principally from sinks and urinals; manufacturers' refuse is poured in constantly both by day and night; thus there are continual fluctuations in the hourly discharge. The flow of sewage is at its maximum during the day and minimum during the night. The maximum flow in an hour has been found, in the case of Wimbledon, to amount to 7·4 per cent., and the discharge in twelve hours to 66 per cent. of the total daily discharge, so that a possible maximum flow of 8 per cent. in an hour, and 70 per cent. in twelve hours, must be kept in view when arranging the capacity of the drains; if, on the other hand, the drains are too large, there will not be a sufficient flow through them to clear away any sediment and prevent deposit; consequently, care must be taken not to impair the efficiency of the sewer by using pipes of too large a bore. Under ordinary circumstances, they should run about two-thirds full to allow for rainfall. Main sewers should not be less than six inches in internal diameter, as house drains in this country are never less than four inches in diameter; the main sewer should, as a general rule, be larger than its tributaries, but this may in special cases be modified by the gradient. Drains for liquids only may, in some cases, be as small as three inches, but no drain receiving the contents of a soil-pipe should be less than four inches, which is a suitable size.

Amount of Sewage.—The next point to be considered is the amount of sewage to be dealt with, as on this depends, to a great extent, the size and shape of the cross section, and also the current necessary for the sewer or house drain. A careful survey must be made of the whole locality to be drained, including any neighbouring districts whose sewage may have to be included.

Estimate of.—It is customary to base the estimate of the quantity of sewage to be dealt with at so much per head of population for the discharge in 24 hours. An allowance must also be made for the prospective increase of population ; in the case of a town, its present rate of increase as obtained from the census returns of the past ten years would be considered a guide ; this rate would, however, require modification according to a carefully formed opinion as to whether the same rate of increase was likely to be maintained. Attention should also be given to the industrial and manufacturing possibilities of the locality, as they may not only affect the amount of sewage to be dealt with but also its character. The estimate should be framed so as to provide for the probable requirements during the next twenty-five to thirty years of the different portions of the district to be drained, as it is not always practicable to maintain a constant allowance throughout.

Water Supply as Guide.—The water supply of the district may be considered as affording a constant daily supply of sewage of equal amount.

Admission of Rainfall.—The admission of the rainfall to the drains complicates the question, as it is difficult to calculate the exact amount of rainfall to be allowed for, even when it is limited to that collected from roofs, back-yards, paved surfaces, etc., as a considerable proportion finds some other outlet.

The nature of the surface drained, and its inclination, must be considered in connection with the question of admission of surface water.

The surface water from rural or uncovered areas only arrives at the sewers by slow degrees, and a great deal passes off as subsoil water, and by evaporation.

The surface water of towns is for the most part so impure as to necessitate its being treated as foul water.

One inch rainfall in an hour only occurs in very severe storms, such as happen only at distant intervals of time in any part of England, so that an allowance of that amount to be carried off in an hour should be ample ; and even when greater rainfalls have been recorded, it would not be advisable on that account to further increase the size of the sewers, as the increased section would injure their efficiency under ordinary circumstances, and any excessive rain, being of short duration, would pass off in a few hours. Mr. Symons, at Camden Town, in 1878, gauged a rainfall at the rate of 12 inches an hour ; this intensity was, however, only maintained for 30 seconds.

For house drains taking surface water from roofs, a rainfall of two inches per hour is sometimes provided, on account of the suddenness with which it will pass into the drains.

The Metropolitan sewers were constructed on the assumption that they would have to convey a rainfall of ·01 inch per hour in addition to the allowance of five cubic feet of sewage per head of the population per diem. Five-eighths of this rainfall only was expected to reach the sewers, the remaining three-eighths being absorbed or evaporated.

Mr. W. Santo Crimp is of opinion that where a town is situated upon a river or stream, the water of which is used for drinking purposes, the

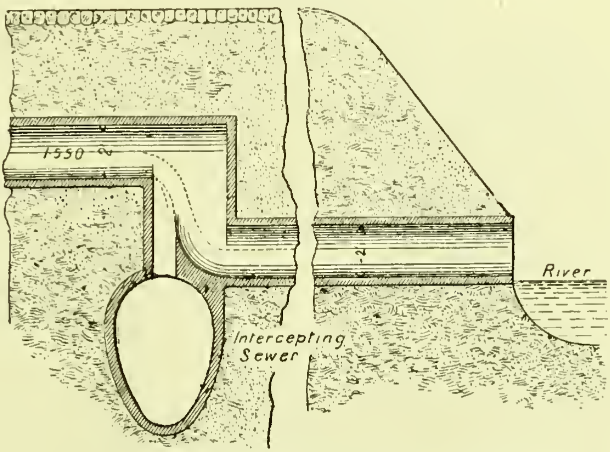


Fig. 24.—Method of intercepting large and pure rainfalls from sewers, and admitting small and impure rainfalls.

rain water should be separated from the sewage to the fullest possible extent, but that towns situated on the sea coasts, on estuaries, and on rivers, the water of which is not so used for domestic purposes, may be satisfactorily drained by means of one system of sewers provided with storm-overflows.

The interceptor designed by Mr. Baldwin Latham, C.E., is suitable for this purpose ; it is shown in Fig. 24. The arrangement is self-acting, and where there is only a small amount of rain or surface water from the road-gutters it passes into the sewer proper, but as soon as the rainfall increases and the surface water becomes sufficiently clean, it leaps over the opening to the sewer and into the channel for surface water leading it into a river or watercourse. A more elaborate arrangement, also by Mr. Baldwin Latham, is shown in Fig. 25. The width of the opening is capable of adjustment, so as to admit a greater or less amount to the sewer and shut it off altogether if desired. The ball and lever with a float at the other end is intended for automatically closing the entrance to the sewer should the surface water channel get flooded.

For the width, etc. of the opening required, see Chap. IV., page 72.

Estimate of Sewage and Rainfall combined.—When estimating the amount of sewage to be dealt with in any particular case, the records of other places will be found good guides; but as a general rule a minimum daily allowance is made of *five cubic feet* or 37·5

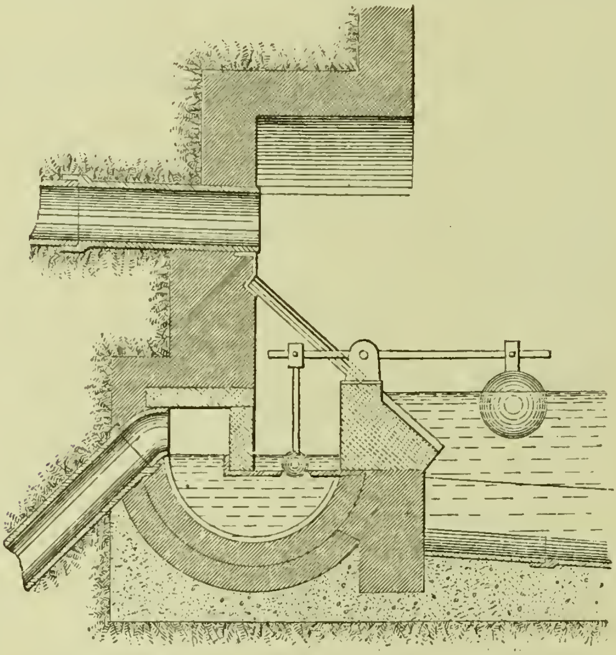


Fig. 25.—Apparatus for excluding flood water from sewer.

gallons per head of population. The maximum during the day is assumed to be *one-half* of this amount, flowing off *in six hours*, or 8 per cent. per hour; this includes the rainfall from roofs and a limited amount of foul water from back-yards, courts, etc.

It has been found by observation that it is only in exceptional cases that the average discharge exceeds 50 gallons per head per day, and the design for the Lower Thames Valley main drainage was based upon an allowance of 40·2 gallons per head, or 250 gallons per house of six inhabitants and under, including rainfall.

When providing a new system of sewers for the City of Edinburgh, the allowance was increased to 42 gallons per head per diem, one-half to pass off in eight hours, the rainfall being taken at two inches.

The amount will, of course, vary considerably with the rainfall, the density of the population of the district, and the proportion of the rainfall admitted to the sewers.

In the Metropolis in 1884, the population varied from 7·3 per acre in the suburban districts to 253 per acre in the more densely populated parts, the corresponding volumes of sewage being ·04 and ·83 cubic feet per acre per minute, and quantities per head 50 gallons and 30 gallons per diem respectively.

Gradient and Velocity of Flow.—Small sewers require a greater inclination than large ones ; pipe sewers require a less inclination than brick drains. The gradients must not be excessive, so as to avoid damage to the sewer.

Minimum Fall.—Latham says that in order to prevent deposit in small sewers or drains, from six inches to nine inches in diameter, a velocity of not less than three feet per second should exist ; for sewers 12 inches to 24 inches, the velocity should not be less than $2\frac{1}{2}$ feet ; and for large sewers, 2 feet per second.

These velocities would require a fall of 1 in 30 for a 4-inch pipe, and 1 in 40 for a 6-inch pipe, and from 1 in 140 to 1 in 200 for pipes from six inches to nine inches in diameter ; from 1 in 400 to 1 in 800 for pipes from 12 inches to 24 inches in diameter, and less than 1 in 800 for larger sewers.

Where possible, however, main sewers should not have a less inclination than 1 in 600, although a considerably smaller gradient is admissible with egg-shaped sewers.

It must be remembered that the velocities here spoken of are *mean* velocities ; the minimum velocity is at the bottom of the channel, or over the invert of a sewer, and for practical purposes may be taken as 76 per cent. of the mean velocity ; it is this velocity upon which the scouring of the channel depends. It varies inversely with the depth of the flow ; in the case of large sewers, it should never be less than 2 feet per second, requiring mean velocities of $2\frac{1}{2}$, $2\frac{3}{4}$, and 3 feet per second when running one-third, one-half, and three-quarters full respectively : for further information see Chap. IV., page 74.

Maximum Fall.—Rankine states that the velocity of the flow in a sewer should never exceed $4\frac{1}{2}$ feet per second, and Rawlinson gives it as his opinion that four feet is a proper limit of velocity, which, if increased to six feet, would destroy any sewer ; this latter velocity is, therefore, often taken as the limit for stoneware drains. The following maximum falls may thus be considered safe for circular pipes :—For 4-inch pipe, $\frac{1}{36}$; for 6-inch pipe, $\frac{1}{60}$; for 9-inch pipe, $\frac{1}{90}$.

These gradients are based on the assumption the pipes are running full or half full.

House Drains are usually less than half full; the pipes, in order to be self-cleansing, should therefore have a greater inclination than that for three feet velocity, and be laid when possible with falls not less than the above for the several sized pipes, but not exceeding $\frac{1}{10}$. Where a fall of $\frac{1}{10}$ or more is necessary, on account of the circumstances of the site, iron pipes should be used, or the drain should be stepped, with manholes at each step.

Table of Discharge of Pipes.—The following Table (taken from Bailey Denton's *Sanitary Engineering*) gives the discharge of different sized pipes, *running full*, at different velocities, and the fall required to produce these velocities :—

TABLE 1.

Diam. of Pipe.	180 ft. per minute. 3 ft. per second.		270 ft. per minute. 4½ ft. per second.		300 ft. per minute. 6 ft. per second.		540 ft. per minute. 9 ft. per second.	
Inches.	Fall.	Gallons per minute.	Fall.	Gallons per minute.	Fall.	Gallons per minute.	Fall.	Gallons per minute.
3	1 in 60	54	1 in 30·4	81	1 in 17·2	108	1 in 7·6	162
4	1 in 92	96	1 in 40·8	144	1 in 23	192	1 in 10·2	288
6	1 in 138	216	1 in 61·2	324	1 in 34·5	432	1 in 15·3	648
9	1 in 207	495	1 in 92	742·5	1 in 51·7	990	1 in 23	1485

The same velocity is produced when the pipes are running *half full*, and to produce these several velocities, half the quantities shown must pass through the pipes.

With a limiting velocity 2·5 feet per second, the following approximate formula for obtaining the necessary fall to be allowed when designing a system of sewerage will be found useful :—

Where H = fall in feet per mile,

R = hydraulic radius,

then
$$H = \frac{7 \cdot 56}{2R}$$

When using this formula it is necessary to assume the diameter of the pipe.

Flushing.—In cases where the available fall from the head of the drain to the junction with the main sewer is less than that required to produce the minimum velocity of three feet per second, it becomes necessary to cleanse the drain occasionally by flushing. Under these circumstances, special apparatus and appliances would have to be used to suit the particular case.

Tables of Sizes of Sewers : Combined System.—The following Table of sizes of sewers at different inclinations for varions urban areas is taken from page 67 of the Minutes of the General Board of Health, July, 1852. It was compiled by Mr. Roc, from results of reliable observations extending over a period of twenty years.

It is, of course, only applicable to the combined system, in which the whole of the rainfall is admitted to the sewers.

TABLE 2.—SHOWING THE QUANTITY OF PAVED OR COVERED SURFACE FROM WHICH CIRCULAR SEWERS (WITH JUNCTIONS PROPERLY CONNECTED) WILL CONVEY AWAY THE WATER COMING FROM A FALL OF RAIN OF ONE INCH IN ONE HOUR, WITH HOUSE DRAINAGE, AS ASCERTAINED IN THE HOLBORN AND FINSBURY DIVISIONS.

	Diameter of Pipes and Sewers in inches.											
	24	30	63	48	60	72	84	96	108	120	132	144
	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres
Level	$38\frac{3}{4}$	$67\frac{1}{4}$	120	277	570	1,020	1,725	2,850	4,125	5,825	7,800	10,100
$\frac{1}{4}''$ in 10′ or 1 in 480	43	75	135	308	630	1,117	1,925	3,025	4,425	6,250	8,300	10,750
$\frac{1}{2}''$ in 10′ or 1 in 240	50	83	—	355	735	1,318	2,225	3,500	5,100	7,175	9,550	12,400
$\frac{3}{4}''$ in 10′ or 1 in 160	63	113	203	460	950	1,692	2,875	4,500	6,575	9,250	12,300	15,950
1″ in 10′ or 1 in 120	78	143	257	590	1,200	2,180	3,700	5,825	7,850	11,050	14,700	19,085
$1\frac{1}{2}''$ in 10′ or 1 in 80	80	165	295	670	1,385	2,486	4,225	6,625				
2″ in 10′ or 1 in 60	115	182	318	730	1,500	2,675	4,550	7,125				

This Table will be a useful guide under most circumstances, but no fixed rule can be given.

The sizes of the pipes in Table 3 (page 36), as in the preceding one, are smaller than those given by calculation, as many circumstances, such as those already mentioned with regard to the dimensions of *sewers*, materially affect the quantities discharged in the several cases.

In order to ascertain the adaptability of a drain or channel of any particular section to the work it will be called upon to perform, it is necessary to be able to calculate the discharge with varying depths of flow, but as this has hitherto been a very troublesome task, hydraulic tables giving more or less fallacious results are resorted to, in order to save time and avoid the drudgery in such calculations. It is, however, necessary in laying out a large system of drainage to study economy and efficiency, and this can only be arrived at by a thorough knowledge of the principles involved.

TABLE 3.—COMBINED SYSTEM SHOWING THE SIZE AND INCLINATION OF MAIN HOUSE DRAINS FOR GIVEN SURFACES, AND THE NUMBER OF HOUSES OF EITHER RATE THEREON, CALCULATED FROM MR. ROE'S TABLE FOR A FALL OF RAIN TWO INCHES IN THE HOUR, AS ASCERTAINED IN THE HOLBORN AND FINSBURY DIVISIONS.

Surface occupied.		Number of Houses of either rate, either of which may be respectively drained.				Diameter and Inclination of Tubes.									
Acres.	Squares of 100 feet.	1st-rate House. Sinks & water on one floor, and water-closets on two floors.	2nd-rate House. Sinks & water on one floor, and water-closet on two floors.	3rd-rate House. Sinks & water on one floor, and water-closet in yard at back.	4th-rate House. Sink & water on one floor, and water-closet in yard at back.	3 inch.	4 inch.	5 inch.	6 inch.	7 inch.	8 inch.	9 inch.	12 inch.	15 inch.	18 inch.
1/8	54	1	2	3	4	1 in 120									
1/4	112	2	4	6	9	,, 20	1 in 120								
7/16	195	3	7	10	15	... ...	,, 40								
1/2	224	5	8	13	18	... ...	,, 30	1 in 80							
6/10	265	5	9	15	21	... ...	,, 20	,, 60							
1	448	10	15	26	36	... ...	... ...	,, 20	1 in 60						
1 1/5	528	11	17	29	40	... ...	... ...	... ...	,, 40	1 in 120					
1 1/2	648	15	23	39	54	... ...	... ...	... ...	,, 20	,, 60	1 in 120				
1 4/5	814	19	28	49	67	... ...	... ...	... ...	... ...	... ...	,, 80				
2 1/10	912	21	32	55	76	... ...	... ...	... ...	... ...	... ...	,, 60	1 in 120			
2 1/2	1,094	25	38	65	90	... ...	... ...	... ...	... ...	... ...	... ...	,, 80			
2 3/4	1,200	27	42	71	99	... ...	... ...	... ...	... ...	... ...	... ...	,, 60			
4 1/2	1,970	45	68	117	162	... ...	... ...	... ...	... ...	... ...	... ...	... ...	1 in 120		
5 3/10	2,308	52	79	136	189	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 80		
5 4/5	2,534	59	88	150	208	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 60	1 in 240	
7 4/5	2,432	79	118	205	284	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 120	
9	3,976	90	135	234	324	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 80	
10	4,404	101	152	263	364	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 60	1 in 240
17	7,400	169	253	439	608	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 120
19 9/10	8,700	200	300	520	720	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	,, 80

CHAPTER III.

THE FLOW OF LIQUID IN PIPES AND OPEN CHANNELS.

It is very evident from what has been stated in the previous chapter that an economical, as well as an efficient system of drainage, depends on the proper selection of the sizes and descriptions of conduits to be employed.

The modern practice is to use channels of relatively much smaller cross section than obtained a few years ago ; this more especially applies to pipes with a circular cross section, for it is often found that old pipes when opened for repairs have never conveyed a stream with a greater depth on the invert than from one-tenth to one-fifth the diameter, and it is manifest in such cases that it would have been more economical to have used smaller pipes.

For instance, a 36-inch pipe flowing with a depth of liquid equal to ·72 inches on the invert, would have a cross section of stream equal to that of a 10-inch pipe flowing 1·1 inches deep, or to a 6-inch pipe flowing 1·38 inches deep, and with each decrease in diameter of pipe there would be a considerable increase of velocity in the stream. In some cases, however, the advantage gained is almost entirely in economy of construction, the increase of velocity being small, *e.g.*, a 6-inch pipe with a depth of 4·98 inches on the invert has only a very small increase in velocity of discharge over a 15-inch pipe, conveying a stream with the same area of cross section but flowing 3 inches deep, and if we continue the comparison we may find even a loss of velocity involved, for by reference to the Tables, pages 87 and 94, it is seen that a 6-inch pipe flowing 5·46 inches deep has a less velocity of current than a 15-inch pipe flowing 3·15 inches deep on the invert, the area of the cross sections of each of these pairs being the same, and the pipes having the same slope.

Comparisons of this nature would be almost hopeless on account of the labour involved, if it were not for the labour-saving Tables (pages 83 *et seq.*) already referred to, and which have been specially prepared for this work.

As glazed pipes are made in such few sizes, it is difficult to adjust them properly under the varying circumstances which arise in practice, but we may expect shortly to find glazed pipes introduced into the market, increasing by one inch in diameter for all the intermediate sizes which can now only be obtained in cast iron.

It is evident that the adjustment of the different descriptions of conduits to the work required of them demands an intimate knowledge on the part of the engineer of their various capabilities and respective merits, as well as the proper application of the best formulæ for calculating their discharge, so as to avoid the serious errors so commonly made in former years, and thus secure at the same time both efficiency and economy.

The sanitary engineer has not only to deal with the flow of sewage in channels and pipes, but also to lay on water for its carriage, and to arrange for adequate flushing where the fall is insufficient under ordinary circumstances.

If a formula has to be used, it is essential to understand its scope and the proper method of applying it, otherwise we may become involved in serious errors which otherwise might be easily avoided.

It appears therefore desirable to give a brief account of the manner in which the most modern formulæ have been gradually elaborated.

The investigation of the motion of water in channels and rivers, etc., has engaged the attention of the most eminent mathematicians and hydraulicians for many centuries; but they sought from the first to formulate the laws which govern its motion on purely mathematical principles.

Galileo, who discovered the law of gravity about the end of the sixteenth century, was one of the first to investigate the flow of water in rivers, and declared that he "found less difficulty in the discovery of the motions of the planets, in spite of their amazing distances, than in his investigations of the flow of water in rivers, which took place before his very eyes."

He considered that the laws of falling bodies applied to the flow of water in rivers, and thus fell into the serious error of strenuously maintaining that the velocity of flow in two channels would be the same with the same total fall irrespective of the length of the channels; and that unless the bends in the course were very sharp they would not exert any retarding effect. He thus succeeded in opposing Bartolotti's scheme for the rectification of the river Vicentio. Galileo died in 1642.

Castelli took up the subject, and in 1628 published a work in which the velocity of the flowing water was for the first time considered as part of the question.

Torricelli, who, as well as Castelli, had been a pupil of Galileo, contributed largely to the science of hydraulics, and published a work on the subject in 1643.

He discovered that the velocity of a jet of water flowing from a small opening in the side of a vessel was, neglecting the resistance, equal to that of bodies falling in space from a height equal to the depth of water above the orifice; and that the velocity of efflux can therefore be obtained by the same formula as that for falling bodies, viz., $v = \sqrt{2gh}$. He also came to the conclusion that the inclination of the stream determined the acceleration of the velocity of the liquid.

Guglielmini about the end of the seventeenth century repeated Torricelli's experiments and developed the "parabolic theory," according to which a particle of water at any depth below the surface moves with the same velocity it would have had if flowing through an orifice at that level, freely into space. A moment's consideration will show that if this principle were correct, the velocity of a stream would be zero at the surface and a maximum at the bottom; the fallacy of such a theory is so apparent that it is quite incredible that it could have been entertained by so eminent a philosopher. It was, however, accepted as true during the whole of the succeeding century.

Grandi also, about the same time, without any foundation or proof, published an even more misleading statement to the effect "that the resistance of the banks of a river terminates at those parts which slide near them without extending to the other parts in the middle," and thus that the liquid above a line drawn joining the summits of the highest points along the bottom and sides could not suffer any impediment from the water lying dormant in the hollows between such points. This theory of an immovable layer of water has lasted until quite recent times.

The error in Guglielmini's theory was pointed out by *Pitot* in 1732, and about the same time the principle of *vis viva* was first applied to flowing water by *Daniel Bernouilli*, thus inaugurating a new and important departure in the theory of hydraulics.

According to Hagen, it was *Brahms* who first endeavoured to ascertain the law by which the cross section of a stream and its gradient influence its velocity; and, in so doing, ascertained that the water in a stream obtains a constant, instead of an accelerated, velocity, as would be expected in accordance with the law of gravity. He attributed this alteration to the friction of the water against the surface of the channel, and considered the resistance thus set up to be proportional to the area of the cross section, divided by the length of the wetted perimeter; thus we get the expression—

$$R=\frac{A}{P}$$

where

R is the hydraulic mean radius, or depth ;

A is the area of the cross section, and

P is the length of the wetted perimeter.

Chezy, a celebrated French engineer, in 1775, was the first to suggest that in the case of a stream in uniform motion, the forces tending to produce acceleration and retardation must be equal.

He considered the acceleration to be due to the action of gravity, the height the water falls in a given distance, and the area of the cross section of the stream ; he adopted at the same time Grandi's theory of a liquid lining.

He included amongst the retarding forces, the length of the channel, also that of the wetted perimeter, and a function of the square of the velocity, and thus obtained the equation—

$$2gh \times A = fv^2 \times l P$$

The value of (f) was intended to be arrived at by experiment ; we thus get

$$v^2 = \frac{2g}{f} \times \frac{A}{P} \times \frac{h}{l}$$

and $v = c\sqrt{RS}$

where $c = \sqrt{\frac{2g}{f}}$

and $R = \frac{A}{P}$ the hydraulic mean depth, or radius ;

and $S = \frac{h}{l}$ the sine of the inclination.

This is the well-known general formula, of which Brahms and Chezy are regarded as the authors, although the name of the latter is more usually associated with it.

The fact that a formula to determine the movement of water could not be established by abstract reasoning alone, was enunciated by Michelotti and Bossut over a hundred years ago ; and recognizing the truth of this statement, Dubuat, in 1779, undertook to investigate the laws of the motion of water.

Dubuat, "the creator of the positive science of running waters," published his great work in 1786. He made a series of experiments, based on very careful measurements, by means of specially constructed wooden channels of small dimensions, and also on the Canal du Jard, and the river Haine, in France. He made 125 experiments in all, 89 on pipes, and 36 on open channels. The greater part of the channels and pipes experimented with had very small cross sections.

He adopted the Chezy formula, and at the same time the erroneous theory of Grandi, and formulated the following two laws :—

1. The motive force is due entirely to the inclination of the surface of the water.

2. When the motion is uniform, the retarding and accelerating forces are equal.

He also stated that the resistance to motion is entirely independent of the weight or pressure of the water, so that its friction upon the surfaces of channels and pipes differs essentially in nature from that which obtains between solid bodies.

Dubuat's formula is a complicated one and tedious to work with, not being readily adapted for logarithmic computation ; it was, however, used by English engineers for upwards of sixty years, as it was supposed to be more reliable than any other then known formula.

I need not give it here as it is quite out of date, and I am dealing more with the historical aspect of the question.

Venturi, in 1798, pointed out a great many causes which were at work, and contributed to retard the velocity of the flow of a river, such as the eddies caused by variations in the hollows in the bed of the stream, the widening and contractions of the bed, the irregularities of the banks, the sinuosities of its course, and the currents which cross each other ; all of which tend to retard the flow, and destroy a portion of the moving force of the water.

Coulomb made his experiments upon the friction between fluids and solids about the end of the 18th and beginning of the 19th centuries, and showed that instead of the resistance being always proportional to the square of the velocity, that it is directly proportional to the velocity, when the latter is less than six inches per second ; that the resistance is more nearly proportional to the square of the velocity when the latter exceeds six inches per second ; and for general purposes, that the resistance in a channel should be represented by the sum of two quantities, the first being proportional to the velocity, and the second bearing the same proportion to the square of the velocity.

De Prony, about the end of the 18th century, came to the following conclusions as the results of his investigations of the experiments made by Dubuat :—

1. " The particles of water in a vertical line in the cross section of a stream move with different velocities, which diminish from the surface to the bottom.

2. " The surface, bottom, and mean velocities stand in a certain relation to each other, which Dubuat, strange to say, finds to be independent of the size and form of the cross section.

3. " A layer of water adheres to the walls of the pipe or channel,

and is therefore to be regarded as the wall proper which surrounds the flowing mass. According to Dubuat's experiments, the adhesive attraction of the walls seems to cease at this layer, so that differences in the material of the walls produce no perceptible change in the resistance.

4. "The particles of water attract each other mutually, and are themselves attracted by the walls of the channel. These attractions (resistances) may in general be expressed by means of two different values, which, however, are supposed to be of the same nature, and comparable with each other."

He published *The Theory of the Flow of Water* in 1804, and adopted Coulomb's theory, but instead of establishing a single function common to both v and v^2, he found it necessary to employ two different constants, and so expressed the value of the resistance by the following equation—

$$RS = av + bv^2$$

From thirty measurements by Dubuat and one by Chezy, De Prony found the values of (a) and (b) for metric measure to be

$$a = 0{\cdot}000044$$
$$b = 0{\cdot}000309$$

and deduced two equations, one suitable for pipes, and the other applicable to open channels.

Between 1814–1815 *Eytelwein*, after comparing the above experiments with fifty-five others by German hydraulicians, modified the above values for (a) and (b). Many authors considered that the De Prony formula might with advantage be simplified by the omission of the quantity (av), which is very small for rivers and for velocities over one metre per second ; the omission of this quantity brings De Prony's formula into agreement with the Chezy formula.

In 1853, *Neville* prepared tables for calculating velocities by his formula based on that of Dubuat, which he modified into the form—

$$v = 140\sqrt{RS} - 11\sqrt[3]{RS}$$

In the formulæ given by different authors, the Chezy formula, with a modification of the value of (c) is adopted ; but in each of these formulæ the coefficient thus chosen remains constant.

Kühlmann and *Weisbach* are exceptions, and give variable values to (c) depending on the value of (v).

Captain *Humphreys* and Lieutenant *Abbot* were employed by the American Government to prepare a project for the regulation of the lower Mississippi, in order to control the river and its tributaries, and so prevent the serious inundations which affected a large tract of country from the Ohio to below New Orleans.

They were engaged for ten years, viz., from 1850 to 1860, in determining the laws of the flow of water in the Mississippi, as they were not satisfied with the existing formula ; their report was completed in 1861. Their observations were most carefully conducted, repeated measurements being made to ensure accuracy in the results.

They considered that the resistance of the wetted perimeter should be increased by that of the surface, and that the air resistance at the surface was equal in effect to that of the wetted perimeter, and accordingly they made

$$R = \frac{A}{P + W}$$

where W is the length of water surface in the cross section.

The fact that the velocities at the bottom and surface were found by them to be unequal, the latter being in excess of the former, tends to disprove their conclusion, which also has not been borne out by more recent experiments.

The American formula is very complicated, though it has been modified by the authors to render it suitable for use in connection with small streams ; it is also only adapted for streams with a very gentle slope, and it is not to be recommended for general use.

In all the formulæ advocated by the preceding authorities, the variations in the roughness of the wetted perimeter, and in the slope, are not considered to affect the coefficients ; and until recently but little has been done to establish the formulæ for the flow of water on a more satisfactory basis, notwithstanding the fact that errors of from 30 to 50 per cent. were involved in their application. The American formula certainly gives better results than this when suitably applied, but, as already explained, its range of usefulness is very limited.

The incorrect design of the cross section of many of the French canals has been attributed by Valées, a French engineer, to too great reliance having been placed by the designers on such formulæ, resulting, in many instances, in serious disasters and loss of life.

It was found that the cast-iron pipes for the supply of water to Grenoble and Toulouse became encrusted with tubercular excrescences, after being only a few years in use, to such a degree as to seriously affect their capacity to supply the necessary water to those towns.

It thus became an urgent matter to investigate the whole subject, and, if possible, to discover by some means a reliable method for conducting the calculations for such purposes.

Darcy and Bazin's Formula.—Monsieur H. Darcy, Inspecteur Générale des Ponts et Chaussées, observed that the greatest quantity of water was delivered in a given time by those pipes which had the smoothest surfaces, and he came to the conclusion that similar phenomena must occur in open channels.

Being a man of great scientific knowledge, and endowed with a talent for patient investigation, he was well adapted to conduct the experiments, which he at once undertook. He began his researches on the discharge of pipes in 1850, and his work on the subject was published in 1857.

In the previous year, with the sanction of the Minister of Public Works, he began similar experiments with open channels.

He made 198 experiments with pipes of different substances, and of all sizes up to $11\frac{1}{2}$ inches in diameter, and one of $19\frac{1}{2}$ inches; some of the pipes were made of new cast iron, coated and uncoated, others were composed of lead, wrought iron, and even glass.

In order to investigate the laws of flow of water in open channels, he had an experimental canal made of wood on the Canal de Bourgogne near Dijon. It was 2 metres wide, 1 deep, and about 600 metres long. It was so constructed that he could vary the inclination and also the cross section at pleasure, and also line it with a great variety of substances. The Canal de Bourgogne was utilized for the supply of the water which was discharged into the river L'Ouche. A specially constructed reservoir was employed for admitting the water into the experimental canal.

M. H. Darcy died in 1858, after completing the preliminary arrangements for his valuable experiments, and the work was continued by his assistant, M. H. Bazin, Ingénieur des Ponts et Chaussées.

The observations were made with the greatest care, and compared with those made by other hydraulicians. About 500 gaugings were investigated, and the results published in 1865.

The results of Darcy's researches are as follows :—

1. That for velocities up to four inches per second, the resistance to the flow of water is sensibly proportional to the velocity, so that

$$\mathrm{RS} = av$$

where (a) is a coefficient varying with the condition and nature of the wetted perimeter.

2. That for higher velocities the resistance was proportional to the square of the velocity, and therefore that

$$\mathrm{RS} = b_1 v^2.$$

3. He confirmed Dubuat's discovery that the resistance decreased as the mean radius increased, and therefore that (b_1) could be best expressed by making

$$b_1 = a + \frac{b}{\mathrm{R}}$$

the value of (b) being determined by experiment.

He thus obtained the expression

$$v = \left(\frac{1}{a + \frac{b}{\mathrm{R}}}\right)^{\frac{1}{2}} \sqrt{\mathrm{RS}} = c\sqrt{\mathrm{RS}}$$

As the values of the coefficients (a) and (b) depend on the infinitely varying nature of the interior surfaces of the pipes or channels which occur, in practice it is not possible to lay down definite values suitable to every case.

Bazin observed that the coefficient (c) increased with an increase of slope, but considered it of too small moment to be provided for in his formula. He also noticed that a greater value of (c) is obtained with a semicircular cross section than with a rectangular. He similarly found that Darcy was correct in his anticipations that his formula was equally applicable to open channels, and in order to provide for variations in the nature of the wetted perimeter, M. H. Bazin established four classes intended to represent the corresponding different degrees of roughness, and to which he allotted different coefficients.

For the sake of simplicity the formula can be written thus :—

$$v = \left\{ \frac{1}{a\left(1 + \frac{b}{R}\right)} \right\}^{\frac{1}{2}} \sqrt{RS}$$

This expression gives (c) a constant value for the same mean radius, and is quite irrespective of the slope of the channel.

The above formula has been modified for convenience of calculation in English measure, as given below :—

Notation.—

v = the mean velocity in feet per second.
Q = the discharge in cubic feet per second.
R = the mean hydraulic radius or depth in feet.
S = the sine of the inclination of the water surface.
A = the sectional area of the stream in feet.
h = the head of water in feet.
l = length of pipe or channel in feet, measured along the slope.
d = the diameter of the pipe in feet.
c = the variable coefficient.

For Pipes running Full.—

$$v = \sqrt{\frac{2g}{\zeta}} \sqrt{RS} = k \sqrt{RS}$$

$$\left(\text{where } k = \sqrt{\frac{2g}{\zeta}}\right)$$

$$Q = Av$$

The value of (ζ) for new pipes is found from

$$\zeta = 0{\cdot}005\left(1 + \frac{1}{12d}\right)$$

and for old iron pipes

$$\zeta = 0{\cdot}01\left(1 + \frac{1}{12d}\right)$$

Since $R = \frac{d}{4}$ for pipes running full or half full, we may express the above equations thus :—

$$v = k\sqrt{\frac{d}{4}S} = \frac{k}{2}\sqrt{dS}$$

$$Q = \frac{\pi d^2}{4}v$$

The values of (ζ) and (k) for different sizes of pipe can be obtained from Table 47 on pages 105 and 106.

It is sometimes required to ascertain the size of a pipe necessary for the discharge of a definite quantity of liquid. For this purpose, Q and S being known, the diameter of the pipe can be approximately determined in the first place from the formula

$$d = 0{\cdot}2216\sqrt[5]{\frac{Q^2}{S}} \text{ for new pipes,}$$

$$\text{and } d = 0{\cdot}2541\sqrt[5]{\frac{Q^2}{S}} \text{ for lightly encrusted pipes.}$$

The value of (d) thus found will furnish a sufficiently near value for (ζ) from either of the formulæ already given for that purpose, according to circumstances.

Having thus determined (ζ), (d) may be accurately obtained from the equation

$$d = \sqrt{\frac{32\zeta Q^2}{g\pi^2 S}}$$

For Open Channels.—

$$v = \sqrt{\frac{2g}{\mu}}\sqrt{RS} = c\sqrt{RS}$$

$$\left(\text{where } c = \sqrt{\frac{2g}{\mu}}\right)$$

$$Q = Av$$

$$\text{and } \mu = \alpha\left(1 + \frac{\beta}{R}\right)$$

The two interpolated coefficients (α) and (β) have the following values.

TABLE 4.

Category.	Description of Channel.	Values.	Log. α.
I.	Very smooth circular channels, lined with pure cement, or wood carefully planed	$\alpha = {\cdot}0029435$ $\beta = {\cdot}0984269$	$3{\cdot}4688717$
II.	Smooth circular channels formed with cut stone, cement and sand, brickwork and unplaned planks	$\alpha = {\cdot}0037285$ $\beta = {\cdot}2296629$	$\bar{3}{\cdot}5715340$
III.	Rubble masonry	$\alpha = {\cdot}00470968$ $\beta = {\cdot}82022480$	$\bar{3}{\cdot}6729916$

When in Categories I. and II. angular channels are being considered in place of circular, the values of (c) obtained from the above data must be reduced by 3·5 to 6·2.

The values of (c) for these three categories, corresponding to various values of (R) between 0·1 and 1·0, can be obtained from Table 48 on page 106.

The variations in the degree of roughness of the channels to be met with in practice are of course infinitely great, and more numerous than can conveniently be taken into account with this formula.

Ganguillet and Kutter's Formula.—The latest development of the theory of the motion of water in channels is due to the researches of MM. Ganguillet and Kutter, of Berne, who published the results of their discoveries in 1869 and 1870.

This work was translated into English in 1876 by Mr. Lowis D'A. Jackson, and more recently, in 1888, by Messrs. Rudolph Hering and John C. Trautwine, jun., whose book should be consulted by all who are interested in the flow of liquid, either in pipes or in open channels.

MM. Ganguillet and Kutter personally conducted a great number of experiments, and also availed themselves of all the data of previously recorded experiments.

They sought to replace the two variable coefficients of the Bazin formula by a single variable coefficient, expressing the degree of roughness of the wetted perimeter.

They found that the Chezy formula could be adapted to all cases, and that the value of (c) increases :—

1. With the increase of the hydraulic depth (R), and more especially so when (R) is small.

2. It also increases with the decrease of roughness of the perimeter, this increase being greatest for the smallest value of R.

3. The value of (c) also increases with the decrease of (S), when (R) is greater than one meter, and also in small channels, if the wetted perimeter is very rough in comparison with the area of the cross section.

4. (c) also increases with the increase of (S), when (R) is less than one meter, and when the wetted perimeter is smooth.

It is thus very evident that any formula which makes the velocity constant, either in part or in whole, is erroneous.

In carrying out their inquiry, MM. Ganguillet and Kutter proceeded in a purely empirical manner, employing the graphic method for the comparison of the several gaugings, and eventually found that the following expression for the value of (c) would satisfy all the conditions and give sufficiently accurate results :—

$$c = \frac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right) \frac{n}{\sqrt{R}}}$$

in which (a), (l) and (m) are constants, and (n) the variable coefficient depending upon the roughness of the surface. The value of these constants is, in English measure,

$$a = 41{\cdot}66$$
$$l = 1{\cdot}811 \text{ feet.}$$
$$m = 0{\cdot}00281$$

The mean values of (n) have been arranged by Ganguillet and Kutter in six categories as follows :—

TABLE 5.

Category.	Description of Channel.	Value of (n).
I.	Channels lined with carefully-planed boards, or smooth cement	0·010
II.	Ditto, lined with unplaned boards	0·012
III.	Ditto, with ashlar, or neatly-jointed brickwork	0·013
IV.	Ditto, in rubble masonry	0·017
V.	Ditto, in earth (brooks and rivers)	0·025
VI.	Streams with detritus, or aquatic plants	0·030

The first three categories refer to channels with semicircular cross sections, which give the best results ; with other varieties of cross section higher values of (n) must be employed.

It must be distinctly understood that the above are only mean values, and considerable variations are met with in practice.

The value of (c) can be easily obtained from the above equation by substituting the values of $\left(\frac{l}{n}\right)$ and $\left(a + \frac{m}{S}\right)$ from the Tables Nos. 49 and 50, pages 107 and 108, and simplifying the fraction.

In the case of small pipes and sewers with a steep slope, $\frac{m}{S}$ is so small a quantity that it may be neglected ; and we get in that case

$$c = \frac{a + \frac{l}{n}}{1 + \frac{an}{\sqrt{R}}}$$

Graphic Solution.—A still easier way to find the value of (c) is to solve the expression graphically, as exemplified in the following Diagram, Fig. 26.

If (O) is the origin, and (OX) and (OY) are the axes of rectangular co-ordinates as above, we may make $OF = l$ on a convenient scale, and draw (FB) so that $n = \tan. BDY$, then $OD = \frac{l}{n}$, and (DY) may be laid off on the same scale as (DO) to represent $\left(a + \frac{m}{S}\right)$.

Then
$$AB = OY = \frac{l}{n} + \left(a + \frac{m}{S}\right)$$
$$\text{and } AO = BY = \left(a + \frac{m}{S}\right) n$$
$$\text{and } AX = \left(a + \frac{m}{S}\right) n + \sqrt{R}.$$

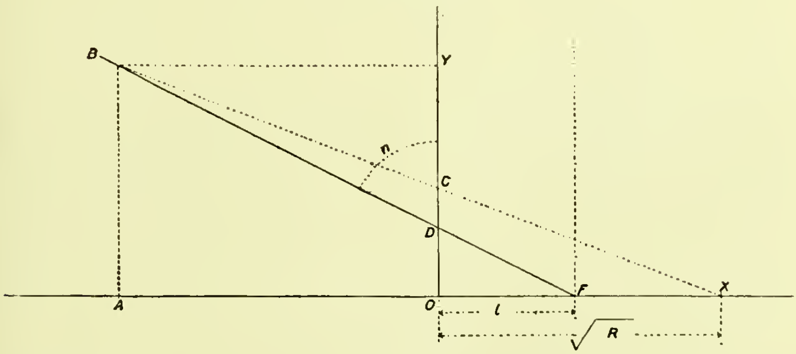


FIG. 26.

Thus we have

$$\frac{OC}{OX} = \frac{AB}{AX} = \frac{a + \frac{l}{n} + \frac{m}{S}}{\left(a + \frac{m}{S}\right) n + \sqrt{R}}$$

$$\text{or } \frac{OC}{\sqrt{R}} = \frac{a + \frac{l}{n} + \frac{m}{S}}{\left(a + \frac{m}{S}\right) n + \sqrt{R}}$$

$$\therefore OC = \frac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right) \frac{n}{\sqrt{R}}} = c$$

In preparing the Diagram, the values of the different quantities parallel to (OX) must be plotted to the same scale as that chosen for the value of the constant (l), and similarly those measured on the axis of Y must be laid off to the same scale, though not necessarily the same as that for (l).

As $\left(\frac{m}{S}\right)$ is constant for any particular slope, and (n) may vary, the locus (B) of the intersection of the (n) lines with the horizontal line BY, where $OY = \frac{l}{n} + a + \frac{m}{S}$ is a curve of the form of an equilateral hyperbola convex towards the origin, and called a slope curve. Each slope has its own curve.

The Diagram on Plate LXI.* is similar to that invented by MM. Ganguillet and Kutter, but the maximum slope, $S = 1$ has been taken in place of $S = \infty$.

The ($\sqrt{R}$) and (l) are represented on the scale of four inches to one foot; thus $OF = l = 1{\cdot}811$ feet, is represented by 7·245 inches.

It is from this point (F), thus located, that the whole of the (n) lines, representing the different degrees of roughness by their inclination to the axes of co-ordinates, radiate.

The scale for the value of (c) is laid off on the axis of (Y), five inches being made to represent ($c = 100$).

The direction of the (n) lines is obtained by setting off on a horizontal line at a distance ($c = 200$) from (O) along the axis of (Y), values of (n) from 0·008 to 0·025 multiplied by 200. These distances are measured to the left from a line drawn through the point (F) parallel to the axis of (Y); other points are obtained by setting off in a similar way, values of (n) from 0·025 to 0·050 multiplied by 100 on a second horizontal line drawn through a point in axis of (Y) at a distance ($c = 100$) from axis of (X).

The following Table gives the offsets already described for the graphic representation of the (n) lines in the Diagram.

It is convenient to deduct the value of (l) or (OF) in plotting, and measure the offsets from the axis of (Y); the deduction is $l = 1{\cdot}8113$ feet = 7·245 inches on scale.

TABLE 6.—OFFSETS FOR THE (n) LINES.

Distance from O on OY.	n.	$n \times 400$. Inches.	$n \times 400 - l$. Inches.
$c = 100$ or 5 inches.	·050	20	− 12·755
	·045	18	− 10·755
	·040	16	− 8·755
	·035	14	− 6·755
	·030	12	− 4·755
		$n \times 800$. Inches.	$n \times 800 - l$. Inches.
$c = 200$ or 10 inches.	·025	20	− 12·755
	·020	16	− 8·755
	·015	12	− 4·755
	·012	9·6	− 2·355
	·010	8·0	− 0·755
	·009	7·2	+ 0·045
	·008	6·4	+ 0·845

* Placed at end of book for convenience when in use.

The horizontal distances given in this Table are calculated so as to be on the same scale as the $\sqrt{R}$; and lines drawn from F, through the points thus fixed, give the positions for the (n) lines which represent the effect of roughness.

Table No. 9 of ordinates on pages 55, 56, has been specially compiled in order to facilitate the drawing of the slope curves required for the construction of the Diagram ; each slope has a curve of its own. The following values of the constants were taken for the purpose of calculating the ordinates :—

TABLE 7.

Constant.	Value.	Logarithm.
a	41·6604676	1·6197242
m	0·0028075	$\bar{3}$·4483281
$l=\sqrt{3\cdot280899}$	1·811325 feet.	0·2579964

By the aid of the Diagram, Plate LXI., when any three of the quantities (R), (S), (n) or (c) are given, the fourth can be readily found.

The Diagram can also be made still more useful by the addition proposed by Mr. Hering, viz. :

as $v=c\sqrt{RS}$

then $$\frac{v}{\sqrt{R}}=\frac{c}{\sqrt{\frac{1}{S}}} \text{ and } \frac{v}{c}=\frac{\sqrt{R}}{\sqrt{\frac{1}{S}}}.$$

Thus, if we lay off a series of values of $\sqrt{\frac{1}{S}}$ on the vertical ordinate, on which the value of (c) is obtained and to the same scale ; then with a parallel ruler join the point representing the value of the $\sqrt{R}$ with the point on the axis of (Y) corresponding to the value of $\sqrt{\frac{1}{S}}$ in the case under consideration ; the intersection of a line parallel to the one thus obtained through the point representing the value of (c) gives on the axis of (X) the value of (v).

In order to deal with small quantities on the scales, multiples may be used, taking care to maintain the proportion. Table 55 on page 126 gives some values of the reciprocals of the $\sqrt{S}$.

Another adaptation of the Diagram is useful in the case of streams and rivers, as it enables the relation between the mean and maximum velocities to be readily determined. This is effected by the following additional construction :—

Draw a line parallel to OY through a point in OX at a distance of 1·0 (on scale for the $\sqrt{R}$) from O, but on the lower side of OX. Set off on this line a distance equal to 25·35 on the scale of (c), and mark the point thus found. A line joining it with any value of (c) on OY gives the proportion between the mean and maximum velocities.

Relative Accuracy of Formulæ.—MM. Ganguillet and Kutter claim that out of 236 gaugings compared by them, 22 of the results were in favour of the formula of Humphreys and Abbot, 49 in favour of that of Bazin, and 165 in favour of their own.

This being so, it shows how little reliance should be placed on still older formulæ and the hydraulic tables calculated by their aid which figure in so many engineering hand-books.

All the necessary calculations for the value (c) in Kutter's formula are now so easily made by the graphic method, that there is no longer any excuse for employing them, especially so when the Tables 24 to 43, pages 83 to 102, giving the areas of segmental cross sections in the case of pipes of the usual sizes between 3 inches and 36 inches, for various depths of stream on the inverts are employed. Tables 44 and 45 give areas of cross section and values of R and $\sqrt{R}$ of egg-shaped sewers. These Tables, which have been specially compiled, as already stated, for this work, also give the corresponding values of $\sqrt{R}$ for each depth on invert, so that a variety of problems connected with the flow of liquid in channels of a circular section can now be readily worked out, without the laborious processes that were formerly necessary.

A Table, No. 50, page 108, of the values of S, $\sqrt{S}$, and $\left(a + \frac{m}{S}\right)$ has also been specially prepared to simplify the solution of Kutter's formula.

The extreme utility of these labour-saving Tables will be shown in the worked examples.

The great difficulty in using Ganguillet and Kutter's formula is the selection of the proper coefficient of roughness, especially in the case of rivers and streams, as no absolute value is obtainable.

For channels lined with timber or masonry, or for pipes, the difficulty is not so great, the constants in that case being few and sufficiently well defined, but in the case of ordinary canals and rivers the case is different, the coefficients having a much greater range. Judgment and experience are therefore required in using Ganguillet and Kutter's formula. I have compiled a Table (page 125) giving the maximum and minimum values of (n) under certain circumstances, and also included a Table (page 126) of the average variations in the value of (n) according to Mr. Albert Wollheim, C.E.

The value of (n) may also be selected so as to cover the minor losses of head in the case of pipes under pressure, and thus to simplify still further the labour involved in working out problems of this nature.

If great care and accuracy is observed in laying new well glazed stone-ware pipe, drain pipes (n) will be found to vary from ·010 to ·011, but as this perfect condition is liable to deterioration from incrustation and subsidence, the value of (n) may increase to ·013 for drains in a fair condition, and to ·015 where in a bad condition with dislocated joints and solids deposited on the inverts. In ordinary calculations for glazed pipes $n = ·013$ is generally used, and $n = ·015$ for brick sewers, so as to allow for deterioration; but when calculating the discharge of new pipe and brick sewers, the values of (n) would be taken as ·011 and ·013 respectively.

In the case of water mains as ordinarily laid with bends, undulations, and other irregularities arising from imperfect moulding and casting of the pipes, the value of (n) has been also found in practice to be as nearly as possible ·013; if, however, the mains had been uniformly calibrated tubes laid in straight lines with uniform slope, the value of (n) would have been ·0125 or even ·012.

Flynn's Modification of Kutter's Formula.—The value of (c) in Kutter's formula, with a slope of 1 in 1000, and $n = ·013$ is thus expressed for slopes up to 1 in 2640:—

$$c = \frac{41·6 + \frac{1·811}{·013} + \frac{·00281}{·001}}{1 + \left(41·6 + \frac{·00281}{·001}\right)\frac{·013}{\sqrt{R}}}$$

$$\therefore\ c = \frac{183·72}{1 + \left(44·41 \times \frac{·013}{\sqrt{R}}\right)}$$

If we call the numerator on the right hand side of the equation K, for any value of (n) we have:—

$$c = \frac{K}{1 + \left(44·41 \times \frac{n}{\sqrt{R}}\right)} \text{ and } v = c\sqrt{RS}.$$

In the following table the value of (K) is given for the several values of (n).

TABLE 8.—GIVING THE VALUE OF (K) FOR USE IN FLYNN'S MODIFICATION OF KUTTER'S FORMULA.

n.	K.	n.	K.	n.	K.	n.	K.	n.	K.
·009	245·63	·012	195·33	·015	165·14	·018	145·03	·021	130·65
·010	225·51	·013	183·72	·016	157·6	·019	139·73	·022	126·73
·011	209·05	·014	137·77	·017	150·94	·020	134·96	·0225	124·9

Author's Form.—The modification just referred to is intended to save labour in calculation, but is admittedly limited in its application; it appears better, therefore, if the relief sought for can be obtained in another way, to stick to the original formula.

The following is Kutter's formula:—

$$v = \frac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right)\frac{n}{\sqrt{R}}} \sqrt{RS}.$$

The fractional part of the expression represents the value of (c), but there is no necessity for its actual determination, so we may simplify the expression to:—

$$v = \frac{\frac{l}{n} + \left(a + \frac{m}{S}\right)}{\sqrt{R} + \left(a + \frac{m}{S}\right)n} R \sqrt{S}$$

The values of the whole of these quantities:—n, $\frac{l}{n}$, $\left(a + \frac{m}{S}\right)$, $\sqrt{R}$, and $\sqrt{S}$ can be obtained from the Labour Saving Tables provided for the purpose; the numerator of the fraction thus involves only simple addition; the denominator requires the multiplication of the value of $\left(a + \frac{m}{S}\right)$ taken from Table 50, by the value of (n) before adding the amount to the value of the $\sqrt{R}$; the value of (v) can then be readily obtained by the use of logarithms in a few lines, as exemplified in the worked examples.

This method has been employed in preparing the Tables (Nos. 56 and 57, pages 127–169) of velocity and discharge for circular pipes, sewers and conduits running full, and of egg-shaped sewers of standard cross-section flowing two-thirds full. In these two cases the values of (n) have been taken at ·013 and ·015 respectively; the Tables have been calculated to the nearest decimal.

An abbreviated (Table No. 59) from Flynn has also been included where (n) is taken as = ·013; it gives the approximate values of the velocities and discharges of certain special sizes of sewers and inclinations when flowing full depth, two-thirds full depth, and one-third full depth.

Taylor's Water Pipe Discharge Diagrams, drawn and compiled by Mr. E. Brough Taylor, C.E., and Mr. G. Midgley Taylor, C.E.,* in agreement with Messrs. Ganguillet and Kutter's formula, will be found useful for readily solving various problems connected with water supply.

* Published by B. T. Batsford.

TABLE 9.—SLOPE CURVES. PLATE LXI.* ORDINATES IN INCHES.

Sine of Slope.	n = ·050.		n = ·045.		n = ·040.	
	x	y	x	y	x	y
1·0	8·332	3·894	7·499	4·096	6·666	4·347
·1	8·338	3·896	7·504	4·097	6·670	4·349
·01	8·388	3·908	7·549	4·100	6·711	4·361
·005	8·444	3·922	7·600	4·124	6·756	4·375
·002	8·613	3·965	7·752	4·166	6·890	4·417
·001	8·914	4·035	8·023	4·236	7·131	4·488
·0005	9·455	4·175	8·510	4·376	7·564	4·648
·0003	10·204	4·362	9·183	4·563	8·163	4·835
·0002	11·140	4·596	10·026	4·797	8·912	5·069
·00015	12·076	4·830	10·868	5·031	9·661	5·303
·00012	13·011	5·064	11·710	5·265	10·409	5·537
·00010					11·158	5·751
·000075					12·655	6·219
	n = ·035.		n = ·030.		n = ·025.	
	x	y	x	y	x	y
1·0	5·832	4·671	4·999	5·102	4·166	5·706
·1	5·836	4·672	5·003	5·103	4·169	5·707
·01	5·872	4·685	5·033	5·116	4·194	5·720
·005	5·911	4·699	5·067	5·130	4·222	5·734
·002	6·029	4·741	5·168	5·172	4·306	5·776
·001	6·240	4·811	5·348	5·242	4·457	5·846
·0005	6·619	4·951	5·673	5·383	4·728	5·986
·0003	7·143	5·139	6·122	5·570	5·102	6·174
·0002	7·798	5·372	6·683	5·804	5·570	6·408
·00015	8·452	5·607	7·245	6·038	6·038	6·642
·00012	9·108	5·840	7·807	6·272	6·506	6·875
·00010	9·763	6·074	8·368	6·506	6·974	7·109
·000075	11·073	6·542	9·491	6·974	7·909	7·577
·000060	12·383	7·010	10·614	7·441	8·845	8·045
·000050	13·694	7·478	11·737	7·909	9·781	8·513
·000040			13·422	8·611	11·185	9·215
·000030			16·229	9·781	13·525	10·385
·000025					15·396	11·321

* Placed at end of book for convenience when in use.

TABLE 9.—SLOPE CURVES—*continued.*

Sine of Slope.	$n = \cdot020$.		$n = \cdot015$.		$n = \cdot012$.	
	x	y	x	y	x	y
1·0	3·333	6·611	2·500	8·121	2·000	9·630
·1	3·335	6·613	2·501	8·122	2·001	9·632
·01	3·355	6·625	2·516	8·135	2·013	9·644
·005	3·378	6·639	2·533	8·149	2·027	9·658
·002	3·445	6·681	2·584	8·191	2·067	9·700
·001	3·566	6·752	2·674	8·261	2·139	9·771
·0005	3·782	6·892	2·837	8·401	2·269	9·911
·0003	4·082	7·079	3·061	8·589	2·449	10·098
·0002	4·456	7·313	3·342	8·822	2·674	10·332
·00015	4·830	7·547	3·623	9·057	2·898	10·566
·00012	5·205	7·781	3·903	9·291	3·123	10·800
·00010	5·579	8·015	4·184	9·525	3·347	11·034
·000075	6·328	8·483	4·746	9·992	3·797	11·502
·000060	7·076	8·951	5·307	10·460	4·246	11·970
·000050	7·825	9·419	5·869	10·928	4·695	12·438
·000040	8·948	10·121	6·711	11·630	5·369	13·140
·000030	10·820	11·291	8·115	12·800	6·492	14·309
·000025	12·317	12·226	9·238	13·736	7·390	15·245

Sine of Slope.	$n = \cdot010$.		$n = \cdot009$.		$n = \cdot008$.	
	x	y	x	y	x	y
1·0	1·666	11·140	1·500	12·146	1·333	13·404
·1	1·668	11·141	1·501	12·147	1·334	13·405
·01	1·678	11·154	1·510	12·160	1·342	13·418
·005	1·689	11·168	1·520	12·174	1·351	13·432
·002	1·723	11·210	1·550	12·216	1·378	13·474
·001	1·783	11·280	1·605	12·286	1·426	13·544
·0005	1·891	11·420	1·706	12·427	1·514	13·684
·0003	2·041	11·608	1·837	12·614	1·633	13·872
·0002	2·228	11·842	2·001	12·848	1·782	14·106
·00015	2·415	12·076	2·174	13·082	1·932	14·340
·00012	2·602	12·309	2·342	13·316	2·082	14·574
·00010	2·789	12·543	2·510	13·550		
·000075	3·164	13·011	2·847	14·018		
·000060	3·538	13·479	3·184	14·486		
·000050	3·912	13·947				
·000040	4·474	14·649				

CHAPTER IV.

HYDRAULIC MEMORANDA AND TABLES.

The Pressure at any point in a liquid is proportional to the depth of the point below the surface of the liquid, and is equal to the weight of a column of the liquid of a height equal to the depth below the surface and one unit of area in cross section.

Thus at P, Fig. 27, at a depth of 50 feet in water, a cubic foot of which weighs almost exactly 62·4 lbs., at a temperature of 52·3° Fahr., the pressure on a square inch

$$= 50 \times \frac{1}{144} \times 62{\cdot}4 = 21{\cdot}67 \text{ lbs.}$$

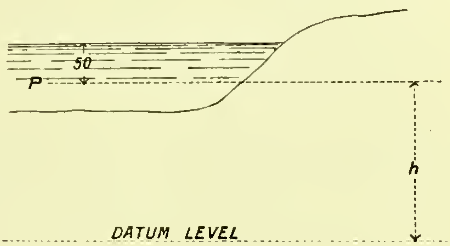


Fig. 27.

Head of Pressure.—The depth of the point P, Fig. 27, below the surface, is called the head of pressure at the point P, or simply the head, and is generally expressed in feet.

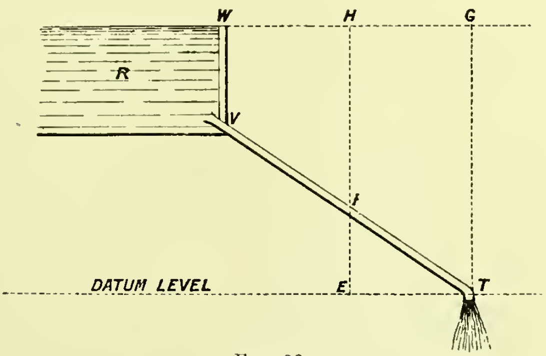


Fig. 28.

Head of Elevation.—The height of the point P above any *datum level* is called the head of elevation of the point P. See Fig. 27.

Loss of Head.—When a liquid is in motion, each particle is constantly moving from a place of greater head to a place of lesser head, and the difference between the two heads is called the *loss of head.* This loss of head may be entirely a loss of *head of pressure*, or entirely a loss of *head of elevation*; or, again, it may partly partake of both.

Thus VT in Fig. 28 is a pipe connected with a reservoir ; at T there is an outlet valve.

When this valve is closed we have at the point P

Head of pressure, HP
,, elevation, EP

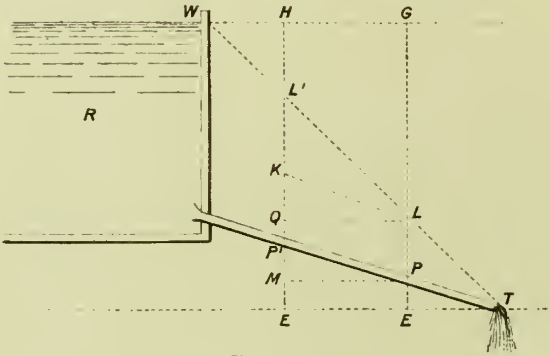


Fig. 29.

At T the head of pressure is GT, and there is no head of elevation with reference to the datum chosen.

When the outlet valve is opened, a different condition of affairs is established. The pressure at T is reduced to zero, and if the resistance of the pipe to the flow of the water is uniform, the pressure at each point of the pipe can be represented by ordinates drawn from it to a straight line WT as shown in Fig. 29.

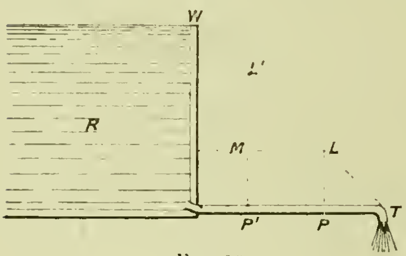


Fig. 30.

Therefore the heads at the point P in the pipe will now consist of

Head of pressure, LP
,, elevation, EP

The head of elevation is thus not altered, but the head of pressure is reduced by the amount LG.

With reference to a second point P_1, in the same Fig., the head of pressure is L_1P_1, and the head of elevation EP_1 ; but the loss of head between the two points is L_1Q ; this *loss of head* is made up of L_1K, the loss of the head of pressure (LK being parallel to PP_1), and loss of *head of elevation*, KQ being equal to P_1M.

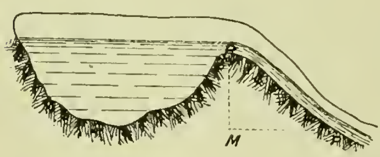


Fig. 31.

If the pipe is horizontal as in Fig. 30, it is clear that the loss of head between the two points P and P_1, is entirely loss of *head of pressure*, and there is no loss of *head of elevation*. On the other hand, if water is flowing in an open channel as in Fig. 31, the loss of head is entirely loss of *head of elevation;* in fact, the water is not flowing under pressure.

When passing water through a pipe the velocity of discharge is found to be less than that due to the total head of pressure in consequence of certain resistances.

In Fig. 32, E_1H_1 is the total head, but the effective head is found to be somewhat less, and may be represented by EH. If we know the value of EH, we can ascertain the velocity and the discharge.

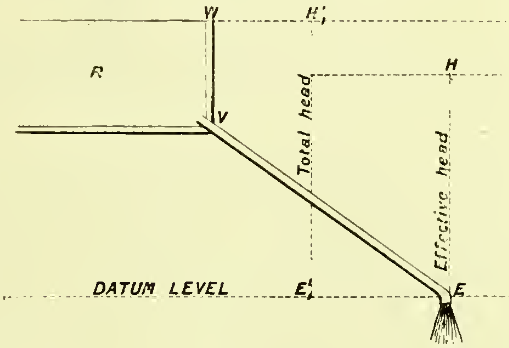


Fig. 32.

In order to do this we have first of all to ascertain the amount of head which is lost from a variety of causes.

The *Resistance of the pipe* causes the *greatest* loss of head, and is quite independent of the inclination of the pipe; there are also some *minor losses*, as follows:—

Loss of Head due to Velocity.—This is lost in causing the water to take up the velocity in the pipe.

$$\text{The energy of motion} = \frac{v^2}{2g} = \frac{v^2}{64{\cdot}4}$$

$$\text{hence } H_v = v^2 \times 0{\cdot}0155.$$

Loss of Head due to Orifice of Entry.—The orifice of entry obstructs to a certain extent the flow of water into the pipe, thus causing a loss

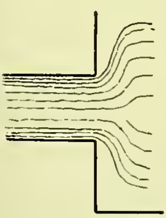


Fig. 33.

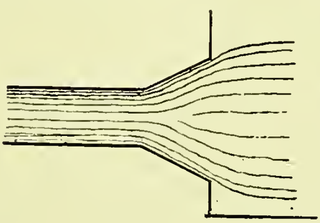


Fig. 34.

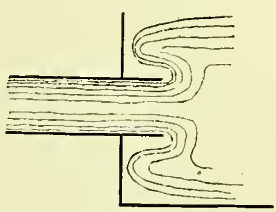


Fig. 35.

of head; it has been found to vary in amount with the form of the orifice.

Fig. 33 is a simple orifice, Fig. 34 is splayed or bell-mouthed, and in Fig. 35 the pipe projects into the reservoir with uniform diameter; the disturbance of the flow of water is indicated in these diagrams. The theoretical velocity (v), with which water flows from an orifice in the side of a vessel at a depth (h) from the surface, is the same as that of a body falling freely by gravity from a height (h), so that $v = \sqrt{2gh}$, but practically the converging currents produce a contraction of the jet,

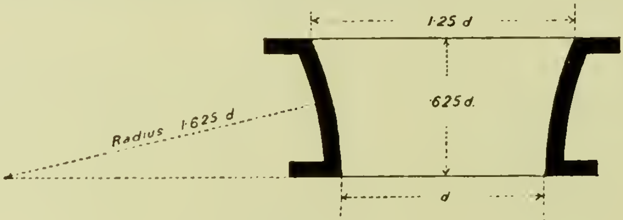


FIG. 36.

which assumes the form of the *vena contracta;* the velocity of discharge is thus modified, and it is found by experiment that it may be allowed for by the insertion of a co-efficient, thus making $v = m\sqrt{2gh}$; the value of (m) varies with the nature of the orifice. Some values of (m) are given below :—

TABLE 10.

Reference No.	Description of Orifice.	m.
I.	Where orifice is in a thin plate, the thickness of which is less than half the smallest dimension of orifice	·625
II.	Ordinary circular orifices under 6½ inches diameter ...	·620
III.	Re-entrant mouth-piece	·5324
IV.	Vena contracta (approximate shape Fig. 36) area measured at the smaller end	·97
V.	Orifice with a cylindrical adjutage; length 2½ to 3 times the least dimension of the orifice...	·82
VI.	With sides converging, length 2½ diameters of orifice, the maximum discharge is at angle of 13½°	·95
VII.	When two sluices in thin plates are so close as to interfere with each other, (m) reduced from ·625 to	·548
VIII.	For sluices of moderate size in lock gates, &c.	·62
IX.	For narrow bridge openings	·82
X.	For very large sluices and bridge openings	·92

If the contraction in any part of an orifice is prevented, as when one side of the orifice coincides with the bottom or side of the vessel, then the co-efficient (m) becomes $m\left(1 + 0{\cdot}152\,\frac{t}{p}\right)$ where p = perimeter of orifice, and t = the length of that portion in which the contraction is prevented. Thus for rectangular orifices we have :—

$$Q = mA\sqrt{2gh}\left(1 + 0{\cdot}152\,\frac{t}{p}\right)$$

and for circular orifices :—

$$Q = mA\sqrt{2gh}\left(1 + 0{\cdot}128\,\frac{t}{p}\right)$$

If it is desired to include the velocity of approach, let

m_1 = the modified value of (m),

h = head due to velocity of approach only,

H = head on sill.

Then

$$m_1 = m\sqrt{1 + \frac{h}{H}}$$

TABLE 11.—TABLE OF CO-EFFICIENTS OF VELOCITY OF DISCHARGE FOR RECTANGULAR ORIFICES, WHERE THE HEIGHT OF THE ORIFICE IS LESS THAN THE WIDTH FOR DIFFERENT HEADS, AS DEDUCED BY RANKINE FROM EXPERIMENTS BY PONCELOT AND LESBROS.

Head divided by Width.	Ratio of height divided by width.					
	1·0	0·5	0·25	0·15	0·1	0·05
	Values of (m).					
·05						·709
·10					·660	·698
·15				·638	·660	·691
·20			·612	·640	·659	·685
·25			·617	·640	·659	·682
·30			·622	·640	·658	·678
·40		·600	·626	·639	·657	·671
·50		·605	·628	·638	·655	·667
·60	·572	·609	·630	·637	·654	·664
·75	·585	·611	·631	·635	·653	·660
1·00	·592	·613	·634	·634	·650	·655
1·50	·598	·616	·632	·632	·645	·650
2·00	·400	·617	·631	·631	·642	·647
2·50	·602	·617	·631	·630	·640	·643
3·50	·604	·616	·629	·629	·637	·638
4·00	·605	·615	·627	·627	·632	·627
6·00	·604	·613	·623	·623	·625	·621
8·00	·602	·611	·619	·619	·618	·616
10·00	·601	·607	·613	·613	·613	·613

By means of the co-efficients for loss of velocity, the loss of *head* due to different descriptions of orifices may be obtained.

Thus $H_o = n \times v^2$.

The values of (n) are given below, the reference numbers in the Table corresponding to the description of orifice entered in previous Table.

TABLE 12.

Reference No.	I.	II. & VIII.	III.	IV.	V. & IX.	VI.	VII.	X.
(n)	·009465	·005970	·011130	·000918	·005098	·001514	·010868	·002396

Loss of Head at Elbow.—Weisbach considers the loss of head at elbows to be due to a contraction formed by the stream. From experiments with a pipe $1\frac{1}{4}$ inches in diameter, he found the loss of head $= \frac{m}{2g} . v^2$, where $m = 0{\cdot}9457 \sin^2 \frac{a}{2} + 2{\cdot}047 \sin^4 \frac{a}{2}$.

TABLE 13.

a	20°	40°	60°	80°	90°	100°	110°	120°	130°	140°
m	0·030	0·139	0·414	0·740	0·984	1·260	1·556	1·861	2·158	2·431
$\frac{m}{2g}$	·0004	·0021	·0064	·0114	·0152	·0195	·0241	·0288	·0335	·0377

Effect of Bends on Pipes and Rivers.—The general formula for loss of head, (H_b), due to bends in rivers, canals, or pipes, is :—

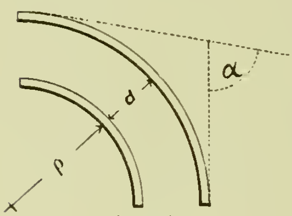


FIG. 37.

$$H_b = m_b n \sin^2 \theta . \frac{v^2}{\sqrt{R}} \text{ (in feet)}$$

where $m_b = {\cdot}5184$

n = number of bends for which allowance is to be made,

θ = number of degrees in one bend, which should not exceed 90°.

The following formula suited to rivers is derived from the Mississippi experiments :—

If H_b = head of water in feet necessary to overcome resistance of bends,

α, β, &c., are the angles between each portion and the direction of the last portion produced,

v = velocity in feet per second,

then—

$$H_b = \frac{v^2(\sin^2\alpha + \sin^2\beta + \&c.)}{134}$$

Circular Bends.—When radius of axis of bend is *greater than five diameters* of the pipe (Fig. 37),

If v = velocity in feet per second,

and θ = number of degrees in bend,

then loss of head in feet, due to resistance of pipe is—

$$H_b = \frac{v^2\theta}{88489} = {\cdot}0000113\, v^2\theta.$$

Weisbach's formula is most accurate for circular bends when the radius of the axis of the bends is *less than five diameters* of the pipe.

$$H_b = \frac{v^2}{2g} \cdot \frac{\theta}{180} \left\{ \cdot 131 + 1 \cdot 847 \left(\frac{d}{2\rho} \right)^{\frac{7}{2}} \right\} = m_b \times v^2 \times \theta,$$

where H_b = loss of head in feet, due to change of direction,

d = internal diameter of pipe in inches.

ρ = radius of bend (centre line) in inches.

θ = angle of bend in degrees.

v = velocity in feet per second.

m_b = constant depending on proportion of d to 2ρ.

TABLE 14.

$\frac{d}{2\rho}$	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
m_b =	·0000113	·0000118	·0000136	·0000177	·0000254	·0000379	·0000570	·0000693	·0001160	·000170

In the case of tubes of rectangular section, (d) being the length of the side parallel to direction of radius of curvature,

$$H_b = \frac{v^2}{2g} \cdot \frac{\theta}{180^\circ} \left\{ \cdot 124 + 3 \cdot 104 \left(\frac{d}{2\rho} \right)^{\frac{7}{2}} \right\} = m_b \times v^2 \times \theta.$$

TABLE 15.

$\frac{d}{2\rho}$	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
m_b	·0000108	·0000117	·0000147	·0000215	·0000344	·0000555	·0000876	·0001334	·0001959	·0002785

According to Hurst, this loss can be obtained from the following Table :—

When the mean velocity of flow is 1 foot per second. For other velocities, multiply by the *Square of the Velocity.*

TABLE 16.

Radius of bend / Diameter of pipe.	Loss of Head for each degree of change of direction.
1	0·000025
1·25	0·000018
1·5	0·000015
2·0	0·000013
3	0·000011
4	0·000011
5	0·000011

To find the loss of head caused by a bend of 20°, of 2″ radius in a 1″ pipe; velocity of flow being 4 feet per second.

$\frac{\text{Radius of bend}}{\text{Diameter of pipe}} = \frac{2}{1}$: hence loss of head $= 0 \cdot 000013 \times 20^\circ \times 4^2$

$= \cdot 00416$ in feet.

Sine of Inclination.—In calculating velocities of discharge it is necessary to understand how to obtain the value of (S) or sine of inclination when the pipes have different gradients.

Now generally, $S = \frac{h}{l}$, but if the pipes are running full, then in Fig. 38 we have

$$S = \frac{h_2}{l_1 + l_2}$$

If, however, the pipes are only partly full, as is the usual case in sewers, then

$S_1 = \frac{h_1}{l_1}$ for the lower length of pipe,

and $S_2 = \frac{h_2 - h_1}{l_2}$ for the upper length of pipe,

and the velocities must be calculated separately.

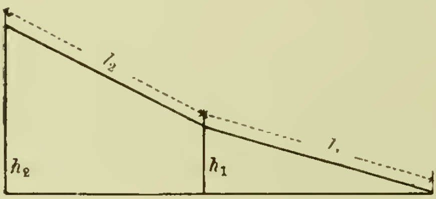


FIG. 38.

Fig. 39 represents a main water pipe running under pressure. (a) and (b) are heads of elevation at either end, with reference to the datum level, and h_1, h_2, h_3, etc., are the heads necessary to overcome

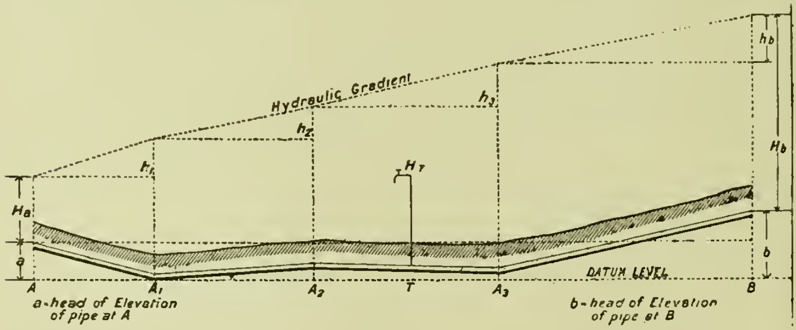


FIG. 39.

the friction of the several pipes constituting the line of main, with the particular discharge required from them.

We thus get

$$(H_a + a) + h_1 + h_2 + h_3 + h_b = H_b + b$$

This would be slightly modified by losses due to bends in the pipes.

The head H_1 available for the supply of a house from this main, and the necessary sized pipe can be obtained by the consideration of the several heads and the duties required from the main in its successive stages.

Mains should never be carried above the *hydraulic gradient*, as such a construction involves practical difficulties in getting rid of the air which accumulates in such portions of the pipe, necessitating special contrivances for that purpose, and also *separate* calculations for the discharging power of the portions of the main on either side of it.

A main from which branch services are to be led should be carried in such a way through the centre of the district it is to serve, so that the services on either side may be of approximately the same value.

Wetted Perimeter and Hydraulic Mean Depth.—In an open channel (Fig. 40), or in the case of a pipe (Fig. 41), the portion of the cross section wetted by the liquid, is called the wetted perimeter; it is

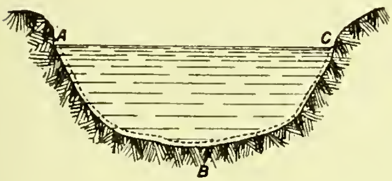


FIG. 40.

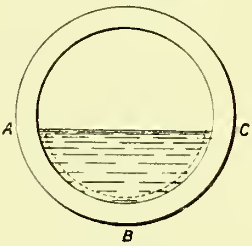


FIG. 41.

also sometimes called the "border." Thus the wetted surface A B C in the above figures are called the wetted perimeters.

The area of the cross section of the stream divided by the wetted perimeter is called the hydraulic mean depth or radius (R).

There is some considerable labour involved in obtaining the areas of cross sections and wetted perimeter of segmental cross sections under the various conditions of depth of stream on invert, but this is almost entirely obviated by the use of the hydraulic Table at page 83, which is suitable for all sizes of pipes; this is followed by other special Tables for the ordinary sized pipes varying from three inches to thirty-six inches in diameter. The hydraulic mean depth may also be readily taken from these tables without involving any calculation whatever.

Syphons.—For the purpose of calculating the discharge of an inverted syphon, it may be treated as an ordinary pipe; but if there are any bends, the resistance offered by them must also be calculated. The head necessary to overcome friction of the bends being ascertained, and deducted from the actual head of water on the syphon, will give the head under which the discharge will take place. In the construction of all syphons arrangements must be made to secure an efficient flush through them, and if this cannot be ensured naturally, special means of flushing must be supplied. For the purposes of calculation, such syphons may be treated as ordinary pipes; the head required to overcome the friction of the bends being ascertained, is then deducted from the actual head on the syphon, and the remainder is the head under which the discharge will take place.

Egg-shaped Sewers.—The following memoranda will be useful when dealing with sewers of this cross section.

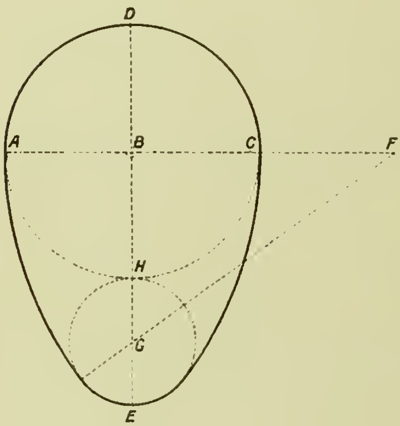


Fig. 42.

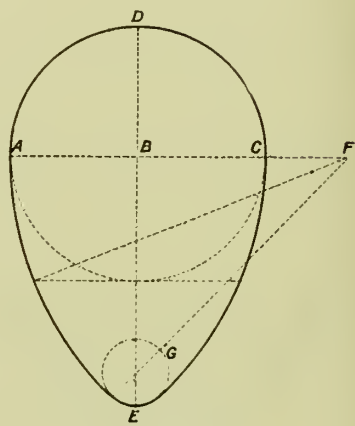


Fig. 43.

In Fig. 42, Phillips' Metropolitan (Standard) (Old Form),

the conjugate diameter $DE = 1\frac{1}{2}\ AC$

$= 1\frac{1}{2}\ d$ (suppose)

radius of invert $= \frac{1}{4}\ d$

radius of side $FA = 1\frac{1}{2}\ d$

TABLE 17.

When full.		$\frac{3}{4}$ths full.	$\frac{2}{3}$rds full.	$\frac{1}{2}$ full.	$\frac{1}{3}$rd full.	$\frac{1}{4}$ full.
Area of whole section	$1{\cdot}1485\ d^2$	$\cdot8795\ d^2$	$\cdot7558\ d^2$	$\cdot5091\ d^2$	$\cdot2840\ d^2$	$\cdot1862\ d^2$
Perimeter of wetted surface	$3{\cdot}9649\ d$	$2{\cdot}6455\ d$	$2{\cdot}39415\ d$	$1{\cdot}8915\ d$	$1{\cdot}3746\ d$	$1{\cdot}1055\ d$
Hydraulic radius...	$\cdot2897\ d$	$\cdot3325\ d$	$\cdot3157\ d$	$\cdot269\ d$	$\cdot2066\ d$	$\cdot1685\ d$

The modification shown in Fig. 43, known as the "New Egg-shape," has been introduced for use when the ordinary flow of liquid is very small. As before,

the conjugate diameter $DE = 1\frac{1}{2}\ AC$

$= 1\frac{1}{2}\ d$ (suppose)

but radius of invert $EG = \frac{1}{8}\ d$ and $FA = 1\frac{1}{3}\ d$

TABLE 18.

When full.		⅔rds full.	⅓rd full.
Area of whole section	1·10612 d^2	·71342 d^2	·27816 d^2
Perimeter of wetted surface...	3·9206 d	2·3498 d	1·4482 d
Hydraulic radius	·2844 d	·3074 d	·1920 d

Tables giving the calculated areas, &c., for egg-shaped sewers are given at pages 103 and 104.

Jackson's peg-top section is represented in Fig. 44; the proportions for the conjugate and transverse diameters and radius of invert are the same as in the last case, but the sides are drawn tangential to the two circles and are equal in length to one half the total depth : the two sections are 220° and 140° respectively.

TABLE 19.

When full.		⅔rds full.	⅓rd full.
Area of whole section	1·03854 d^2	0·64584 d^2	0·24217 d^2
Perimeter of wetted surface...	3·87802 d	2·30722 d	1·27065 d
Hydraulic radius	0·268 d	0·280 d	0·190 d

This form of section is very convenient for calculations for intermediate depths ; it is also more readily constructed than sewers with curved sides, but on the other hand it requires a greater thickness of material when subject to external pressure.

A great variety of other sections for sewers can be obtained from the *Sewerage Engineer's Note-Book*, by Albert Wollheim, A.M.I.C.E.

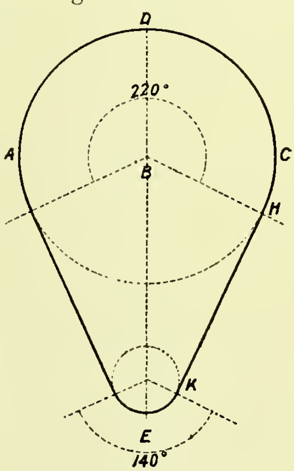


FIG 44.

Discharge of Water over a Notch or Weir, with a clear overfall.—

Let h = height of water at centre of overfall over notch in feet.

w = velocity of approach in feet per second determined by assumed ratio to mean velocity.

l = length of notch or sill in feet.

Q = number of cubic feet discharged per second.

then $Q = \frac{2}{3} mlh \sqrt{2gh}$ when water above sill is not in motion.

When the area of the overfall exceeds one-fifth the area of the channel, a velocity of approach is set up, and

$$Q = \frac{2}{3} m l h \sqrt{2g} \sqrt{h + \cdot 035 v^2} \text{ when water is in motion.}$$

$m = \cdot 665$ when notch is the whole length of the weir.
$= \cdot 613$,, $\frac{1}{2}$,,
$= \cdot 600$,, $\frac{1}{3}$,,
$= \cdot 596$,, $\frac{1}{4}$,,

These values of (m) are for thin edges, as of metal sheets, on one-inch wasteboards ; for broad or round crests the coefficients require reduction as follows :—

If l = length of weir sill.
L = ,, dam, or breadth of channel.
H = head on sill.
D = depth of notch.

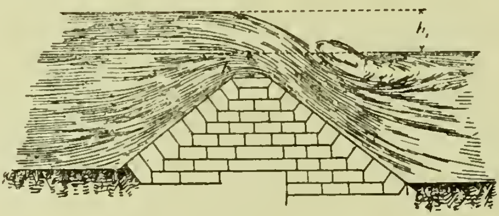


Fig. 45.

we have—

$m = \cdot 5$ for broad-crested or flat-topped weir, and also when channel is attached.

$= \cdot 57 \times \frac{l}{10L}$ for weirs with one-inch crests when (l) is equal to or greater than $\frac{L}{4}$.

$= \cdot 6$ for overfalls when (l) is greater than $\frac{L}{4}$ and less than $\frac{L}{3}$; and V-shaped notches when L equals $\frac{D}{2}$.

$= \cdot 62$ for V-shaped notches when $l = \frac{D}{4}$.

$= \cdot 552$ for weirs when $l = L$, and H is greater than one-third the height of the barrier.

When the overfall has channels in continuation of its sides the coefficients are reduced by 18 to 33 per cent., but, however, if the fall to the channel is over three feet no reduction as a rule is made.

Instead of employing the above formula to include velocity of approach, it is sometimes considered better to use a new coefficient (m_1) obtained as follows :—

Let h_v = head due to the velocity of approach,

then $$m_1 = m\left\{\left(1+\frac{h_v}{h}\right)^{\frac{3}{2}} - \left(\frac{h_v}{h}\right)^{\frac{3}{2}}\right\}$$

To Raise a River a certain Height by a Weir.—(Fig. 45.)

If Q = discharge of river in cubic feet per second.

h = height by which river is to be raised in feet.

h_2 = depth of top of weir below original surface of water necessary to raise surface by height h_1.

h_v = head corresponding to velocity of approach.

l = length of weir in feet.

m = coefficient of contraction = ·628.

Ascertain first the height (h) due to the quantity Q (taking m = ·628). If this is less than (h_1), the top of the weir must rise to a height ($h_1 - h$) above original level of water. If (h_1) is less than (h) the weir must be a submerged one, and (h_2) is found from the following equation :—

$$h_2 = \frac{Q}{ml\sqrt{2gh_1}} - \frac{2}{3}h_1$$

or, taking velocity of approach into account :—

$$h_2 = \frac{Q}{ml\sqrt{2g(h_1+h_v)}} - \frac{2}{3}\,\frac{(h_1+h_v)^{\frac{3}{2}} - h_v^{\frac{3}{2}}}{\sqrt{h_1+h_v}}$$

To find *Increased Velocity caused by Obstructions* in river :—

If A = area of cross section of river in feet.

A_1 = „ obstructed portion „

v = velocity before obstruction, as gauged in feet per second.

v_1 = velocity after obstruction.

then $$v_1 = \frac{A_v}{A - A_1}\ ; \quad A_1 = \frac{A(v_1 - v)}{v_1}$$

The velocity v_1 should not be greater than the materials of the bed of river will bear.

To find *Height or Afflux* to which river will be raised by obstruction :—

If Q = volume of water passing down in feet per second.

L = mean width of waterway above contracted part in feet.

l = „ „ at contracted part.

p = mean depth at contracted part in feet.

m = ·8, ·7, or ·6, according as cutwater is curved and acute, obtuse, or square to the channel.

x = rise in channel caused by obstruction.

then $$x = \frac{Q^2}{2g}\left\{\frac{1}{m^2l^2p^2} - \frac{1}{L^2(p+x)^2}\right\}$$

The distance the backwater will extend above the bridge is from 1·5 to 1·9 x multiplied by the cotangent of the original slope of the river.

Obstructed Overfalls.—These occur where there are obstacles on the sill of an overfall, which affect the discharge by a reduction of the area of section, and the resulting contractions.

By Francis' formula, where the length of the weir sill equals or exceeds the head, we get

$$Q = \frac{2}{3} m \sqrt{2g}(l - 0{\cdot}1nh)h^{\frac{3}{2}} = 5{\cdot}35m(l - 0{\cdot}1nh)h^{\frac{3}{2}}$$

where $n =$ the number of end contractions.
$= 2$, when there is no central obstruction, each central obstacle involving two additional end contractions.
$l =$ length of weir sill.
$h =$ head on the weir from still water.
and $m = 0{\cdot}6228$.

In case the weir sill has the same breadth as the channel of supply, $n = o$; and then

$$Q = 3{\cdot}332lh^{\frac{3}{2}}$$

Gauging a Stream.—The formula, pages 67 and 68, may also be used for gauging small streams and watercourses. A weir is placed across the stream (Fig. 46), formed with a plank B well puddled, with a plate of thin iron A screwed to it, having a notch cut out of such a size as shall fulfil the following conditions:—

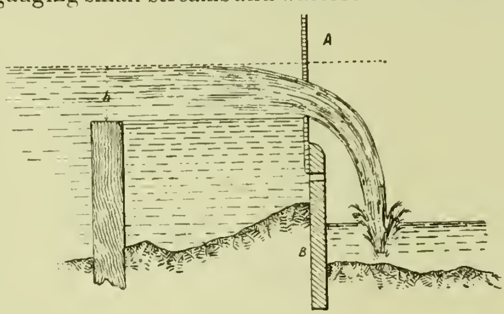


Fig. 46.

The section of the water flowing over the weir at the maximum should not exceed one-fifth of the channel immediately above it, so as to avoid having to allow for velocity of approach, (h) must be greater than ·1968 feet, or say ·2 feet (better from six inches to twenty-four inches), and less than one-third the height of the barrier as it approaches the weir. There must be a clear outfall below the weir, so that there is no backwater. A plank one inch thick may be used instead of the iron plate, but the edges up stream must be sharp and true in level and square; they should be levelled off at an angle of 45° on the downstream side. If the probable discharge is under forty cubic feet per second the sill should be placed about six inches above the tail-race, and for the calculation (m) may be taken = ·623.

When the discharge exceeds the above amount, it will be necessary to use a notch the full width of the channel; a place for the weir should be selected where the channel is regular in width and inclination. Having fixed the level at this point before constructing the weir, make the sill from one to five feet above it; the ends of the opening should be squared with planking, and by means of a gauge at either end the mean value for (h) may be obtained. The value of (m) may in this case be taken as ·666.

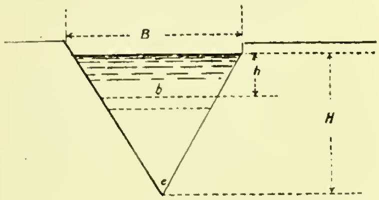


Fig. 47.

To estimate (h), a stake C is driven behind the weir with the top level with bottom of notch, and the depth of water flowing over is measured by a rule held on its summit. The stake must be far enough from the weir to be beyond the depression of the water, from two to three feet in small weirs to twenty or twenty-five in large ones.

Triangular Notch.—

If B = the breadth of stream on notch (Fig. 47).

H = ,, depth ,, ,,

then $Q = \frac{4}{15} m B \sqrt{2g} H^{\frac{3}{2}}$

The ratio between B and H is constant if the notch is equilateral, and then with varying discharges the value of (m) is more constant,

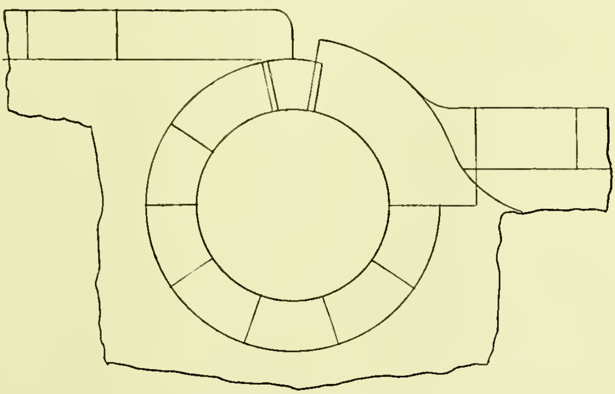


Fig. 48.—Section of Separating Weir.

and = 0·617 for a sharp-edged triangular notch. This shape of notch is suitable for accurate gaugings.

Separating Weirs.—A section of a separating weir as designed by Sir A. R. Binnie for the Bradford Waterworks is shown in Fig. 48; the object is to separate the coloured water which occurs in high floods from the purer water of ordinary flow. This is effected by the velocity imparted to the water discharged over a weir causing it to follow a parabolic path; the distance the water is projected depends on the depth of water on the weir and the consequent amount of velocity. In Fig. 49 let (h) be the head of water discharging over a weir, then, according to Professor Unwin, it is sufficiently accurate for practical purposes to assume the mean velocity of the water passing over the weir

$$= \frac{2}{3} \sqrt{2gh}$$

Then if x = the width of the orifice ef, and y = the difference of level a, e, of the two edges, and if a particle passes from a to f in (t) seconds, then

$$y = \frac{1}{2} g t^2$$

$$x = \frac{2}{3} \sqrt{2gh} \times t$$

$$\therefore y = \frac{9}{16} \cdot \frac{x^2}{h}$$

This gives the width for any given difference of level which the jet will just pass over with a head (h).

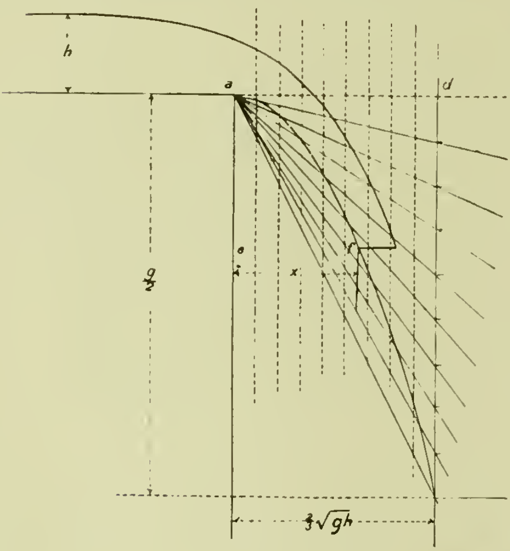


Fig. 49.

If in addition there is a velocity of approach, (h) must include the head necessary to give that velocity, which is $\left(\frac{v}{2g}\right)^2$, if ($v$) is the velocity of approach in feet per second. In order to describe the path of the jet, set off ab vertically $= \frac{1}{2} g$ on any scale; and bc horizontally $= \frac{2}{3} \sqrt{gh}$; divide ad and dc into an equal number of equal parts, join a with the divisions on dc, and verticals through the divisions on ab, the intersections of these lines will give the parabolic path of the underside of the jet.

Measurement of Velocity.—It is not always practicable to obtain the discharge of a stream by constructing a dam across it, nor is that to be derived from the observed slope and cross section always to be relied on; it is then necessary to ascertain the velocity of flow by careful observation.

In the case of a small stream a "flume," or timber framework covered with close boarding, sufficiently large to form a lining to the bed and sides of the stream, may be employed ; it should be from 100 to 200 feet in length and of uniform cross section; the upper end is protected by stout piling, so that the whole of the water is obliged to pass through it—in this way the cross section of the stream can be readily determined. The discharge can then be accurately obtained from the observed mean velocity in the " flume " and the cross section of the stream.

If this cannot be arranged, then a straight reach of the river should be chosen with a fairly uniform cross section, the dimensions of which would have to be obtained by soundings and a marked cord stretched across the river ; the positions of the soundings may also be arrived at by angular observations from the bank. The level of the water at different times can be determined by a fixed gauge and a good 18-inch level and staves reading to millimetres ; if still greater accuracy is required, Boyden's hook gauge for determining the exact level of the surface of the water can be used. The hook is at the bottom of the gauge, and is immersed in the water until the point coincides with the surface, which takes place when the distorted reflection of light caused by capillary attraction ceases. The gauge is provided with a vernier, so that the true reading to ·001 of a foot can be ascertained ; if the point of the hook is provided with a small knob, a levelling staff can be set up on it for use with a level.

The *Surface Velocity* may be obtained by means of floats placed in the centre of the stream, such as a hollow floating ball which just rises above the surface, or a partly-filled bottle, and then observing its time of transit over a known distance ; the velocity thus obtained along the centre thread of the river and over its deepest part is the maximum velocity, and the mean vertical velocity can be measured by a rod or tube weighted so as to float vertically, and of such a length as to reach nearly to the bottom of the river.

Captain Humphreys and Lieutenant Abbot, when gauging the Mississippi, found that the best way of obtaining the velocity was to suspend kegs without top or bottom, ballasted with strips of lead, by a rope to surface floats of light pine 3 ft. 5 in. × 5 ft. 5 in. × ·5 in., or of tin of an ellipsoidal form with axes 5·5 in. and 1·5 in. The kegs were nine inches in height, six inches in diameter, with rope one-tenth of an inch in diameter for observations not more than five feet below the surface, and were twelve inches in height and eight inches in diameter, with rope rather less than one-fifth of an inch in diameter for greater depths. The length of the rope was adjusted to the required depth for the observation. The observations were taken for a length of 200 feet.

The screw current meter was used by M. Révy for gauging the Paranà and La Plata.

Relation between Mean and Surface Velocities, &c.—In large rivers with very small inclination, Captain Humphreys and Lieutenant Abbot found, from observations in the Mississippi, that the velocities at various depths vary as the abscissæ of a parabola whose axis is parallel to the water's surface and represents the maximum velocity, and is in calm weather, at a depth below the surface, equal to three-tenths of the depth of the water at the section. This varies with the wind, but the mid-depth velocity does not vary, and is therefore the most convenient to observe. The mean velocity was found to increase gradually, and quite uniformly, from the banks to the thread of the current. The following equations represent the relation between the measured mid-depth velocity V_1 in any vertical plane, and the velocities in calm weather at other depths in the same plane.

$$\text{Mean velocity } V_2 = V_1 - \frac{1}{12}\sqrt{bv}$$

$$\text{Maximum velocity } V_3 = V_2 + \sqrt{bv}\left(\frac{1}{3} + \frac{d_1(d_1 - d)}{d^2}\right)$$

$$\text{Surface velocity } V_0 = V_3 - \sqrt{bv}\left(\frac{d_1}{d}\right)^2$$

$$\text{Bottom velocity } V_4 = V_3 - \sqrt{bv}\left(1 - \frac{d_1}{d}\right)^2$$

Where $b = {\cdot}1856$ for rivers having a depth $d = 30$ feet.

$b = \dfrac{1{\cdot}69}{\sqrt{d + 1{\cdot}5}}$ for less values of d.

$d_1 = {\cdot}317\,d$ and is the depth of the axis of the parabola below the surface.

$v =$ is the approximate mean velocity of the river, obtained by taking mean of observed velocities at mid-depth as the mean velocity of all the vertical planes.

$V_1 =$ the mid-depth velocity.

Mean Surface and Bottom Velocities.—(Flynn.) "According to the formula of Bazin—

$$v = \frac{c \times v_{max}}{c + 25{\cdot}4} = v_{max}\, 25{\cdot}4 \sqrt{RS}$$

$$v = v_b + 10{\cdot}87 \sqrt{RS}$$

$$\therefore v_b = v - 10{\cdot}87 \sqrt{RS}$$

"In which v = mean velocity in feet per second.

v_{max} = maximum surface velocity in feet per second.

v^b = bottom velocity in feet per second.

R = hydraulic mean depth in feet.

S = sine of slope.

"Rankine states that in open channels, like those of rivers, the ratio of v to v_{max} is given approximately by the following formula of Prony in feet measures :—

$$v = v_{max}\left\{\frac{v_{max} + 7\cdot71}{v_{max} + 10\cdot28}\right\}$$

"The least velocity, or that of the particles in contact with the bed, is almost as much less than the mean velocity as the greatest velocity is greater than the mean. Rankine also states that in ordinary cases the velocities may be taken as bearing to each other nearly the proportions of 3, 4 and 5. In very slow currents they are nearly as 2, 3 and 4.

"The deductions of Dubuat are that the relation of the velocity of the surface to that of the bottom is greatest when the mean velocity is least ; that the ratio is wholly independent of the depth ; the same velocity of surface always corresponds to the same velocity of bed. He observed also, that the mean velocity is a mean proportional between the velocity of the surface and that of the bottom.

"As the result of his experience on rivers of the *largest* class, M. Révy arrived at the following conclusions :—

"1. That, at a given inclination, surface currents are governed by depths alone, and are proportioned to the latter.

"2. That the current at the bottom of a river increases more rapidly than at the surface.

"3. That for the same surface current the bottom current will be greater with the greater depth.

"4. That the mean current is the actual arithmetic mean between that at the surface and that at the bottom.

"5. That the greatest current is always at the surface, and the smallest at the bottom ; and that as the depth increases, or the surface current becomes greater, they become more equal, until, in great depths and strong currents, they practically become substantially alike."

Mean Velocities from Maximum Surface Velocities.—(Flynn.) "Bazin has given a very useful formula for gauging channels, by means of which the mean velocity can be found from the hydraulic mean depth and the observed maximum surface velocity. For measures in feet this formula is :—

$$v = \frac{c \times v_{max}}{c + 25\cdot4}$$

Now let $c_1 = \dfrac{c}{c + 25\cdot4}$ and $v = c_1 \times v_{ma}$

"The following Table will be found of great service in saving time when using this formula :—

$$v = c_1 \times v_{max}$$

TABLE 20.—GIVING VALUES OF c_1.

Hydraulic mean depth (R) in feet.	Values of c_1. For very even surfaces, fine plastered sides and bed, planed planks, &c.	For even surfaces, such as cut stone, brickwork, unplaned planking, mortar, &c.	For slightly uneven surfaces, such as rubble, masonry.	For uneven surfaces, such as earth.
0·5	·84	·81	·74	·58
0·75	·84	·82	·76	·63
1·0	·85	·82	·77	·65
1·5	·85	·82	·78	·69
2·0	·85	·83	·79	·71
2·5	·85	·83	·79	·72
3·0	·85	·83	·80	·73
3·5	·85	·83	·80	·74
4·0	·85	·83	·81	·75
5·0	·85	·83	·81	·76
6·0	·85	·84	·81	·77
7·0	·85	·84	·81	·78
8·0	·85	·84	·81	·78
9·0	·85	·84	·82	·78
10·	·85	·84	·82	·78
11·	·85	·84	·82	·78
12·	·85	·84	·82	·79
13·	·85	·84	.82	·79
14·	·85	·84	·82	·79
15·	·85	·84	·82	·79
16·	·85	·84	·82	·79
17·	·85	·84	·82	·79
18·	·85	·84	·82	·79
19·	·85	·84	·82	·79
20·	·85	·84	·82	·80

Destructive Velocities.—(Flynn.) "Kutter (translation by Jackson) states :—

"The maximum velocities determined by Dubuat, as suitable to channels in various descriptions of soil, are taken from Morin's *Aide Memoire de Mécanique Pratique,* page 63, 1864. The first column in the following Table gives the *safe bottom velocity,* and the second the mean velocity of the cross section ; the formula by which these are calculated is :—

$$v = v_b + 10{\cdot}87 \sqrt{RS}$$

TABLE 21.—GIVING THE SAFE BOTTOM AND MEAN VELOCITIES IN CHANNELS.

Material of channel.	Safe bottom velocity v_b, in feet per second.	Mean velocity v, in feet per second.
Soft brown earth	0·249	0·328
Soft loam	0·499	0·656
Sand	1·000	1·312
Gravel...	1·998	2·625
Pebbles	2·999	3·938
Broken stone, flint	4·003	5·579
Conglomerate. soft slate............	4·988	6·564
Stratified rock	6·006	8·204
Hard rock	10·009	13·127

"We (Ganguillet and Kutter) are unable, for want of observations, to judge how far these figures are trustworthy. The inclinations certainly have no influence in this case, as the corresponding velocities are mutually interdependent, but the variation of the depth of water is most probably of consequence, and in shallower depths the soil of the bottom is possibly less easily and rapidly damaged than in greater depths, under similar conditions of soil and of inclination. Yet this effect is not very large, while that of the actual velocity of the water is of the highest importance. Hence it appears that these figures may be assumed to be rather disproportionately small than too large, and we therefore recommend them more confidently.

"Mr. John Neville, in his hydraulic tables, states that for the materials given in the following table the *mean velocity* per second should not exceed—

0·42 feet in soft alluvial deposits.
0·67 feet in clayey beds.
1·0 feet in sandy and silty beds.
2·0 feet in gravelly earth.
3·0 feet in strong gravelly shingle.
4·0 feet in shingly soil.
5·0 feet in shingly and rock bed.
6·67 feet and upwards in rocky and shingly bed.

"The beds of rivers protected by aquatic plants, however, bear higher velocities than this table would assign, up to two feet per second.

"Water flowing at a high velocity and carrying large quantities of silt, sand and gravel is very destructive to channels, even when constructed of the best masonry.

"Colonel Medley, R.E., had considerable opportunities of observing the abrading power of silt-laden water on the Ganges Canal, India ; and in the *Roorkee Treatise on Civil Engineering*, he writes thus :—

"Brickwork should not be used in contact with currents with such high velocities (15 feet per second). Even the very best brickwork cannot stand the wear and tear for any length of time, and stone should be used for all surfaces in contact with velocities exceeding, say, 10 feet per second."

Abrading and transporting Power of Water.—(Flynn.) Professor J. Le Conte, in his *Elements of Geology*, states :—

"The erosive power of water, or its power of overcoming cohesion, varies as the square of the velocity of the current.

"The *transporting* power of a current varies as the sixth power of the velocity. . . . If the velocity, therefore, be increased ten times, the transporting power is increased 1,000,000 times. A current running three feet per second, or about two miles per hour, will move fragments of stone of the size of a hen's egg, or about three ounces weight. It follows from the above law that a current of ten miles an hour will bear fragments of one and a half tons, and a torrent of twenty miles an hour will carry fragments of 100 tons. We can thus easily understand the destructive effects of mountain torrents when swollen by floods.

"The *transporting* power of water must not be confounded with its *erosive* power. The resistance to be overcome in the one case is *weight*, in the other, cohesion ; the latter varies as the *square*, the former as the sixth power of the velocity.

"In many cases of removal of slightly cohering material, the resistance is a mixture of these two resistances, and the power of removing material will vary at some rate between v^2 and v^6.

Continuing from Flynn, "Silt, sand, gravel and stones lose as much weight in water as a volume of water having an equal cubic content, which is generally about equal to half their weight in air. They are, therefore, easily moved, but, with the exception of silt, their velocity is less than that of the current, and the nearer their specific gravity approaches that of water the nearer their velocity approaches that of the current.

"The English Astronomer Royal, in a discussion at the Institution of Civil Engineers, said that the formula for the transporting power of water was the only instance in physical science, with which he was acquainted, in which the sixth power came really into application.

"Mr. T. Login, C.E., states, as the result of his observations for several years on the Ganges Canal, and other channels, that the abrading and transporting power of water increases in some proportion as the velocity increases, but decreases as the depth decreases.

"Umpfenback gives the size of materials that will be moved in the bottom of small streams, at the following figures :—

TABLE 22.—GIVING THE TRANSPORTING POWER OF WATER.

Surface velocity in metres.	Gravel, diameter in metres.	Surface velocity in feet.	Gravel, diameter in feet.
0·942	0·026	3·091	0·085
1·569	0·052	5·148	0·170
	Cubic metres.		Cubic feet.
2·197	0·00515	7·208	0·182
3·138	0·209	10·296	0·738
4·708	0·618	15·447	21·826

"Chief Engineer Sainjon made observations in the River Loire in France, with the following results :—

Velocity of feet per second......	1·64	3·28	4·92	6·56
Diameter of stone in feet	0·034	0·134	0·325	0·56

"In order to protect the foundations of the Ravi bridge, in India, 15-inch concrete cubes (1·56 cubic feet) were deposited around the piers. It was noted in one case, that with a velocity of probably not less than 10 feet a second, the blocks were moved from a sandy bottom on to a level brick floor protecting the bridge. Although exposed to a more violent current, they were not moved off the flooring. This evidence is somewhat in proof of Smeaton's experience, that quarry stones of about half a cubic foot were not much deranged by a velocity of 11 feet per second, although the soil was washed from under them.

"Experiments made by Mr. T. E. Blackwell, C.E. for the British Government, in the plan of the Main Drainage, show very clearly that the specific gravity of materials has a marked effect upon the mean velocities necessary to move bodies.

"For example, coal of a specific gravity of 1·26 commenced to move in a current of from 1·25 to 1·50 feet per second.

"A second sample of coal, of specific gravity 1·33, did not commence to move until the velocity was 1·50 to 1·75 feet per second.

"A brickbat of specific gravity 2·0, and chalk of specific gravity 2·05, required a velocity of 2·0 to 2·25 feet per second to start them.

"Oolite stone, specific gravity 2·17; brickbat, 2·12; chalk, specific gravity 2·0; broken granite, specific gravity 2·66, required a velocity of 2·0 to 2·25 feet per second to start them.

"Chalk, specific gravity 2·17; brickbats, specific gravity 1·46, required a velocity of from 2·25 to 2·50 feet per second to start them.

"Oolite stone, specific gravity 2·32; flints, specific gravity 2·66; limestone, specific gravity 3·00, required a velocity of 2·5 to 2·75 to start them.

"It was shown in these experiments that after the start of the materials with the current, in no case did the materials to be transported travel at the same rate as the stream, but in every case their progress was considerably less, as a rule, often more than 50 per cent. less than the velocity of the current.

"Mr. Baldwin Latham, in the course of his experiments in sewerage matters, has found that in order to prevent deposits of sewage silt in small sewers or drains, such as those from 6 inches to 9 inches diameter, a mean velocity of not less than 3 feet per second should be produced. Sewers from 12 to 24 inches diameter should have a velocity of not less than 2½ feet per second, and in sewers of larger dimensions in no case should the velocity be less than 2 feet per second.

"Sir John Leslie gives the formula:—

$v = 4\sqrt{a}$ for finding the velocity required to move rounded stones to shingle, in which

v = velocity of water in miles per hour, and

a = the length of the edge of a stone if a cube in feet, or the mean diameter if a rounder stone or boulder, also in feet.

"This formula takes no notice of specific gravity. Chailly has supplied this omission, and he has derived the following formula, which is just sufficient to set bodies in motion:—

$v = 5{\cdot}67 \sqrt{ag}$, in which

a = average diameter of the body to be moved in feet,

g = its specific gravity, and

v = velocity in feet per second.

"Experience on the irrigation canals in Northern India, where rapids are in use, has proved that a boulder rapid, with a flooring composed of boulders not less than eighty pounds in weight each, well packed *on end*, and at a slope of 1 in 15, will *not* stand a mean velocity of 17·4 feet per second."

TABLE 23.—COLLECTION OF USEFUL QUANTITIES WITH LOGARITHMS.

		Logarithm.
	Length.	
π ratio of circumference of circle to its diameter	3·14159265336	0·4971499
1 foot	0·304794 metre	$\bar{1}$·4840071
1 mile	1609·3123 metres	3·2066403
1 metre	3·280899 feet (English)	0·5159929
	Area.	
1 square foot	0·0928997 square metre	$\bar{2}$·9680142
1 square metre	10·764300 square feet	1·0319858
	Volume.	
1 cubic foot	0·0283153 cubic metre	$\bar{2}$·4520213
	6·23210 British imperial gallons	0·7946344
1 British impl. gallon	0·16046 cubic foot	$\bar{1}$·2053654
	0·0045435 cubic metre	$\bar{3}$·6573868
1 cubic metre	35·316585 cubic feet	1·5479787
	220·0966 British imperial gallons	2·3426132
	Water.	
	Weights of Certain Measures.	
1 cubic foot	62·425 pounds	1·7953553
	28·3153 kilograms	1·4520213
1 British impl. gallon	10·0165 pounds	1·0007208
	4·5435 kilograms	0·6573868
1 cubic metre	2204·672 pounds	3·3433340
	Measures of Certain Weights.	
1 pound	0·016019 cubic foot	$\bar{2}$·2046447
	0·099834 British imperial gallon	$\bar{2}$·9992792
	0·00045359 metre	$\bar{4}$·6566660
1 kilogram	0·0353166 cubic foot	$\bar{2}$·5479787
	0·2200966 British imperial gallon	$\bar{1}$·3426132
	0·001 cubic metre	$\bar{3}$·0000000
	Velocity of—	
g accelerating force of gravity (latitude of London)	32·19078 feet per second	1·5077315
$2g$ ditto, ditto	64·38156	1·8087615
g ditto, ditto, Paris	32·18255	1·5076204
$2g$ ditto, ditto	64·36510	1·8086504
g ditto, ditto, New York	32·15945	1·5073086
$2g$ ditto, ditto	64·31890	1·8083386
1 foot per second	0·681818 mile per hour	$\bar{1}$·8336687
1 mile per hour	1·466666 feet per second	0·1663313
1 metre per second	3·280899 feet per second	0·5159929
	Discharge of—	
1 cubic foot per second	0·0283153 cubic metre per second	$\bar{2}$·4520213
	6·23210 British impl. gallons per second	0·7946346
1 B. impl. gallon per sec.	0·004534 cubic metre ,,	$\bar{3}$·6573868
	0·16046 cubic foot ,,	$\bar{1}$·2053654
1 cubic metre per sec.	35·316585 cubic feet ,,	1·5479787
	220·0966 British impl. gallons ,,	2·3426132

The following extract on the value of (g) the acceleration of gravity is from Merriman's *Hydraulics* :—

"The symbol (g) is used in hydraulics to denote the acceleration of gravity ; that is, the increase in velocity per second for a body falling freely in a vacuum at the surface of the earth. . . .

"The following formula of Pierce, which is partly theoretical and partly empirical, gives the value of (g) in feet for any latitude (L), and any elevation (e) above the sea level, (e) being taken in feet :—

$$g = 32{\cdot}0894\ (1 + 0{\cdot}0052375 \sin^2 L)\ (1 - 0{\cdot}0000000957e)$$

and from this its value may be computed for any locality."

TABLE 24.—GENERAL HYDRAULIC TABLE FOR CHANNELS WITH SEGMENTAL CROSS SECTIONS WHERE (d) IS THE DIAMETER IN FEET.

Depth on Invert ÷ by Diameter.	Area of Section = $(d)^2 \times$ by	Wetted Perimeter = $(d) \times$ by	Hydraulic Mean Depth = $(d) \times$ by	Depth on Invert ÷ by Diameter.	Area of Section = $(d)^2 \times$ by	Wetted Perimeter = $(d) \times$ by	Hydraulic Mean Depth = $(d) \times$ by
·001	·000042	·0632997	·0006635	·51	·402698	1·5907967	·2531476
·002	·000119	·0894724	·0013300	·52	·412694	1·6108080	·2562031
·003	·000219	·1095988	·0015872	·53	·422681	1·6309501	·2591626
·004	·000337	·1265750	·0026624	·54	·432656	1·6506024	·2621200
·005	·000471	·1414790	·0033291	·55	·442615	1·6709646	·2648858
·006	·000619	·1550745	·0039916	·56	·452555	1·6910873	·2676119
·007	·000779	·1693205	·0046007	·57	·462470	1·7112585	·2702514
·008	·000952	·1791242	·0053147	·58	·472356	1·7314878	·2728035
·009	·001135	·1900218	·0059730	·59	·482211	1·7517832	·2753687
·010	·001329	·2003346	·0066339	·60	·492028	1·7720548	·2776532
·011	·001533	·2101481	·0072948	·61	·501805	1·7926111	·2799297
·02	·003749	·2837934	·0132103	·62	·511537	1·8131623	·2822242
·03	·006866	·3481659	·0197204	·63	·521119	1·8338193	·2842258
·04	·010538	·4027151	·0261072	·64	·530847	1·8545947	·2862334
·05	·014681	·4514680	·0325183	·65	·540418	1·8754891	·2881476
·06	·019239	·4949337	·0388718	·66	·549925	1·8965261	·2899644
·07	·024168	·5355261	·0451293	·67	·559364	1·9177144	·2916826
·08	·029435	·5735123	·0513242	·68	·568732	1·9390648	·2932954
·09	·035012	·6093856	·0574545	·69	·578022	1·9606029	·2948185
·10	·040875	·6435009	·0635197	·70	·587230	1·9823139	·2962346
·11	·047006	·6761327	·0695218	·71	·596350	2·0042423	·2975439
·12	·053385	·7074828	·0754576	·72	·605378	2·0263950	·2987462
·13	·059999	·7377252	·0813297	·73	·614308	2·0487917	·2998390
·14	·066833	·7669937	·0871363	·74	·623135	2·0714517	·3008204
·15	·073875	·7953979	·0928780	·75	·631852	2·0943950	·3016891
·16	·081112	·8230332	·0985525	·76	·640453	2·1176479	·3024360
·17	·088536	·8499773	·1041620	·77	·648933	2·1412340	·3030650
·18	·096135	·8762987	·1097050	·78	·657284	2·1651828	·3035695
·19	·103900	·9020529	·1151810	·79	·665500	2·1895252	·3039472
·20	·111824	·9272943	·1205910	·80	·673574	2·2142983	·3041912
·21	·119898	·9520674	·1259340	·81	·681498	2·2395397	·3043027
·22	·128114	·9764098	·1312090	·82	·689263	2·2652939	·3042710
·23	·136465	1·0003586	·1364160	·83	·696862	2·2916153	·3040920
·24	·144945	1·0239447	·1415550	·84	·704286	2·3185594	·3037602
·25	·153546	1·0471976	·1466250	·85	·711523	2·3461947	·3032668
·26	·162263	1·0701409	·1516270	·86	·718565	2·3745989	·3026047
·27	·171090	1·0928009	·1565610	·87	·725399	2·4038674	·3017633
·28	·180020	1·1151976	·1614240	·88	·732013	2·4341098	·3007313
·29	·189048	1·1373503	·1662170	·89	·738392	2·4654599	·2994940
·30	·198168	1·1592787	·1709408	·90	·744523	2·4980927	·2980366
·31	·207376	1·1809897	·1759999	·91	·750386	2·5322070	·2963368
·32	·216666	1·2025278	·1801755	·92	·755963	2·5680803	·2943689
·33	·226034	1·2238789	·1846863	·93	·761230	2·6060665	·2920992
·34	·235473	1·2450665	·1891243	·94	·766159	2·6466589	·2894816
·35	·244980	1·2661035	·1934913	·95	·770717	2·6901246	·2864985
·36	·254551	1·2869979	·1977867	·96	·774860	2·7388774	·2829115
·37	·264179	1·3077733	·2020067	·97	·778532	2·7934267	·2787014
·38	·273861	1·3284303	·2061539	·98	·781649	2·8577992	·2735143
·39	·283593	1·3489815	·2102275	·989	·783865	2·9314445	·2673989
·40	·293370	1·3694378	·2142310	·990	·784069	2·9412580	·2665487
·41	·303187	1·3898094	·2181500	·991	·784263	2·9515708	·2657104
·42	·313042	1·4101048	·2219991	·992	·784446	2·9624684	·2647947
·43	·322928	1·4303341	·2257711	·993	·784619	2·9722721	·2639795
·44	·332843	1·4505053	·2294670	·994	·784779	2·9865181	·2627739
·45	·342783	1·4706280	·2330861	·995	·784927	3·0001136	·2616330
·46	·352742	1·4909902	·2365823	·996	·785061	3·0150176	·2603835
·47	·362717	1·5106425	·2401077	·997	·785179	3·0319938	·2589645
·48	·372704	1·5307846	·2434724	·998	·785279	3·0521202	·2572897
·49	·382700	1·5507959	·2467765	·999	·785356	3·1382929	·2502494
·50	·392699	1·5707963	·2500000	1·000	·785398	3·1415926	·2500000

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet	$\sqrt{R}$ in Feet.
·001	·003	·000002	·00016	·01287	·51	1·53	·025168	·06328	·25156
·002	·006	·000007	·00033	·01823	·52	1·56	·025793	·06405	·25308
·003	·009	·000013	·00039	·01991	·53	1·59	·026417	·06479	·25454
·004	·012	·000021	·00066	·02579	·54	1·62	·027041	·06553	·25598
·005	·015	·000029	·00083	·02884	·55	1·65	·027663	·06622	·25733
·006	·018	·000038	·00099	·03158	·56	1·68	·028284	·06690	·25865
·007	·021	·000048	·00115	·03391	·57	1·71	·028904	·06756	·25992
·008	·024	·000059	·00132	·03645	·58	1·74	·029522	·06820	·26106
·009	·027	·000071	·00149	·03864	·59	1·77	·030138	·06884	·26237
·010	·030	·000083	·00165	·04072	·60	1·80	·030752	·06941	·26346
·011	·033	·000096	·00182	·04270	·61	1·83	·031363	·06998	·26454
·02	·06	·000234	·00330	·05746	·62	1·86	·031971	·07055	·26562
·03	·09	·000429	·00493	·07021	·63	1·89	·032601	·07105	·26656
·04	·12	·000659	·00652	·08078	·64	1·92	·033178	·07155	·26750
·05	·15	·000917	·00812	·09016	·65	1·95	·033776	·07203	·26839
·06	·18	·001202	·00971	·09857	·66	1·98	·034370	·07249	·26924
·07	·21	·001510	·01128	·10621	·67	2·01	·034960	·07292	·27003
·08	·24	·001839	·01283	·11327	·68	2·04	·035546	·07332	·27078
·09	·27	·002188	·01436	·11984	·69	2·07	·036126	·07370	·27148
·10	·30	·002554	·01587	·12601	·70	2·10	·036702	·07405	·27213
·11	·33	·002937	·01738	·13183	·71	2·13	·037272	·07438	·27273
·12	·36	·003336	·01886	·13734	·72	2·16	·037836	·07468	·27328
·13	·39	·003749	·02033	·14259	·73	2·19	·038394	·07495	·27378
·14	·42	·004177	·02178	·14762	·74	2·22	·038946	·07520	·27423
·15	·45	·004617	·02321	·15237	·75	2·25	·039491	·07542	·27463
·16	.48	·005069	·02463	·15696	·76	2·28	·040028	·07560	·27497
·17	·51	·005533	·02604	·16137	·77	2·31	·040558	·07576	·27525
·18	·54	·006008	·02742	·16560	·78	2·34	·041080	·07589	·27548
·19	·57	·006494	·02879	·16969	·79	2·37	·041594	·07598	·27565
·20	·60	·006989	·03014	·17363	·80	2·40	·042198	·07604	·27576
·21	·63	·007493	·03148	·17743	·81	2·43	·042594	·07607	·27581
·22	·66	·008007	·03280	·18111	·82	2·46	·043079	·07606	·27580
·23	·69	·008529	·03410	·18467	·83	2·49	·043551	·07602	·27572
·24	·72	·009059	·03538	·18811	·84	2·52	·044017	·07594	·27557
·25	·75	·009596	·03665	·19156	·85	2·55	·044470	·07581	·27534
·26	·78	·010141	·03790	·19469	·86	2·58	·044910	·07565	·27504
·27	·81	·010693	·03914	·19783	·87	2·61	·045337	·07544	·27466
·28	·84	·011251	·04035	·20088	·88	2·64	·045751	·07518	·27419
·29	·87	·011815	·04155	·20384	·89	2·67	·046149	·07487	·27363
·30	·90	·012385	·04273	·20672	·90	2·70	·046533	·07450	·27296
·31	·93	·012961	·04399	·20976	·91	2·73	·046899	·07408	·27218
·32	·96	·013541	·04504	·21223	·92	2·76	·047248	·07359	·27128
·33	·99	·014127	·04617	·21487	·93	2·79	·047577	·07302	·27023
·34	1·02	·014717	·04728	·21744	·94	2·82	·047885	·07237	·26901
·35	1·05	·015311	·04837	·21993	·95	2·85	·048169	·07162	·26762
·36	1·08	·015909	·04944	·22236	·96	2·88	·048429	·07072	·26594
·37	1·11	·016511	·05050	·22472	·97	2·91	·048658	·06967	·26396
·38	1·14	·017116	·05153	·22702	·98	2·94	·048853	·06837	·26149
·39	1·17	·017724	·05255	·22925	·989	2·967	·048991	·06684	·25855
·40	1·20	·018335	·05355	·23062	·990	2·970	·049004	·06663	·25814
·41	1·23	·018949	·05453	·23353	·991	2·973	·049016	·06642	·25773
·42	1·26	·019565	·05549	·23558	·992	2·976	·049028	·06619	·25729
·43	1·29	·020183	·05644	·23757	·993	2·979	·049039	·06599	·25689
·44	1·32	·020802	·05736	·23951	·994	2·982	·049049	·06569	·25630
·45	1·35	·021423	·05827	·24139	·995	2·985	·049058	·06540	·25575
·46	1·38	·022046	·05914	·24319	·996	2·988	·049066	·06509	·25513
·47	1·41	·022669	·06002	·24500	·997	2·991	·049073	·06474	·25444
·48	1·44	·023294	·06086	·24671	·998	2·994	·049079	·06432	·25303
·49	1·47	·023919	·06169	·24838	·999	2·997	·049084	·06256	·25070
·50	1·50	·024543	·06250	·25000	1·000	3·000	·049087	·06250	·25000

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·004	·000004	·00022	·01487	·51	2·04	·044744	·08438	·29048
·002	·008	·000013	·00044	·02105	·52	2·08	·045855	·08540	·29223
·003	·012	·000024	·00052	·02300	·53	2·12	·046964	·08638	·29391
·004	·016	·000037	·00088	·02979	·54	2·16	·048073	·08737	·29559
·005	·020	·000052	·00110	·03331	·55	2·20	·049179	·08829	·29714
·006	·024	·000068	·00133	·03647	·56	2·24	·050284	·08920	·29867
·007	·028	·000086	·00153	·03916	·57	2·28	·051385	·09218	·30014
·008	·032	·000106	·00177	·04208	·58	2·32	·052484	·09093	·30155
·009	·036	·000126	·00199	·04462	·59	2·36	·053579	·09175	·30291
·010	·040	·000147	·00221	·04702	·60	2·40	·054669	·09693	·31134
·011	·044	·000170	·00243	·04931	·61	2·44	·055756	·09330	·30546
·02	·08	·000416	·00440	·06635	·62	2·48	·056837	·09404	·30666
·03	·12	·000763	·00657	·08107	·63	2·52	·057913	·09474	·30780
·04	·16	·001171	·00870	·09320	·64	2·56	·058983	·09541	·30889
·05	·20	·001632	·01083	·10411	·65	2·60	·060048	·09604	·30991
·06	·24	·002137	·01295	·11383	·66	2·64	·061214	·09665	·31089
·07	·28	·002685	·01504	·12265	·67	2·68	·062174	·09722	·31181
·08	·32	·003270	·01710	·13079	·68	2·72	·063192	·09776	·31267
·09	·36	·003890	·01915	·13836	·69	2·76	·064222	·09827	·31348
·10	·40	·004542	·02117	·14551	·70	2·80	·065248	·09874	·31423
·11	·44	·005223	·02317	·15222	·71	2·84	·066261	·09918	·31493
·12	·48	·005932	·02515	·15859	·72	2·88	·067264	·09958	·31556
·13	·52	·006666	·02710	·16465	·73	2·92	·068256	·09971	·31577
·14	·56	·007426	·02886	·17042	·74	2·96	·069237	·10027	·31662
·15	·60	·008208	·03095	·17595	·75	3·00	·070206	·10056	·31711
·16	·64	·009012	·03285	·18124	·76	3·04	·071161	·10081	·31750
·17	·68	·009837	·03472	·18633	·77	3·08	·072103	·10102	·31784
·18	·72	·010682	·03658	·19122	·78	3·12	·073031	·10119	·31810
·19	·76	·011544	·03839	·19594	·79	3·16	·073944	·10131	·31830
·20	·80	·012425	·04019	·20049	·80	3·20	·074841	·10139	·31842
·21	·84	·013322	·04197	·20488	·81	3·24	·075722	·10143	·31848
·22	·88	·014235	·04323	·20913	·82	3·28	·076584	·10142	·31847
·23	·92	·015152	·04547	·21324	·83	3·32	·077429	·10136	·31837
·24	·96	·016105	·04718	·21722	·84	3·36	·078254	·10125	·31821
·25	1·00	·017061	·04887	·22107	·85	3·40	·079058	·10132	·31794
·26	1·04	·018029	·05054	·22532	·86	3·44	·079840	·10084	·31756
·27	1·08	·019010	·05099	·22582	·87	3.48	·080599	·10081	·31715
·28	1·12	·020002	·05380	·23196	·88	3·52	·081333	·10024	·31661
·29	1·16	·021005	·05540	·23538	·89	3·56	·082043	·09983	·31596
·30	1·20	·022018	·05698	·23870	·90	3·60	·082724	·09934	·31519
·31	1·24	·023042	·05853	·24193	·91	3·64	·083378	·09877	·31429
·32	1·28	·024074	·06005	·24506	·92	3·68	·083995	·09812	·31324
·33	1·32	·025115	·05156	·24811	·93	3·72	·084581	·09736	·31203
·34	1·36	·026164	·06304	·25108	·94	3·76	·085128	·09649	·31063
·35	1·40	·027220	·06448	·25396	·95	3·80	·085635	·09549	·30903
·36	1·44	·028283	·06592	·25676	·96	3·84	·086095	·09430	·30708
·37	1·48	·029353	·06733	·25948	·97	3·88	·086503	·09290	·30479
·38	1·52	·030429	·06871	·26214	·98	3·92	·086849	·09117	·30194
·39	1·56	·031510	·07008	·26471	·989	3·956	·087096	·08913	·29855
·40	1·60	·032596	·07141	·26722	·990	3·960	·087118	·08884	·29807
·41	1·64	·033687	·07271	·26966	·991	3·964	·087140	·08857	·29760
·42	1·68	·034782	·07399	·27202	·992	3·968	·087161	·08826	·29709
·43	1·72	·035881	·07525	·27433	·993	3·972	·087179	·08799	·29663
·44	1·76	·036982	·07648	·27656	·994	3·976	·087197	·08762	·29595
·45	1·80	·038087	·07769	·27873	·995	3·980	·087214	·08721	·29531
·46	1·84	·039194	·07886	·28082	·996	3·984	·087229	·08679	·29460
·47	1·88	·040302	·08003	·28290	·997	3·988	·087242	·08632	·29380
·48	1·92	·041411	·08115	·28488	·998	3·992	·087253	·08576	·29285
·49	1·96	·042522	·08225	·28680	·999	3·996	·087262	·08341	·28881
·50	2·00	·043633	·08333	·28867	1·000	4·000	·087266	·08333	·28867

TABLE 27.—PIPE FIVE INCHES IN DIAMETER.

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·005	·0000072	·00027	·01662	·51	2·55	·069913	·10547	·32477
·002	·010	·0000206	·00055	·02354	·52	2·60	·071648	·10675	·32672
·003	·015	·0000380	·00066	·02571	·53	2·65	·073382	·10798	·32860
·004	·020	·0000585	·00110	·03330	·54	2·70	·075113	·10921	·33047
·005	·025	·0000817	·00138	·03724	·55	2·75	·076842	·11036	·33221
·006	·030	·0001074	·00166	·04078	·56	2·80	·078568	·11150	·33392
·007	·035	·0001352	·00191	·04378	·57	2·85	·080289	·11260	·33556
·008	·040	·0001652	·00221	·04705	·58	2·90	·082006	·11366	·33714
·009	·045	·0001970	·00248	·04988	·59	2·95	·083717	·11469	·33866
·010	·050	·0002307	·00276	·05257	·60	3·00	·085421	·11569	·34013
·011	·055	·0002661	·00303	·05513	·61	3·05	·087120	·11663	·34152
·02	·10	·0006508	·00550	·07419	·62	3·10	·088808	·11755	·34285
·03	·15	·0011920	·00821	·09064	·63	3·15	·090489	·11842	·34413
·04	·20	·0018295	·01087	·10429	·64	3·20	·092160	·11926	·34534
·05	·25	·0025487	·01354	·11640	·65	3·25	·093822	·12006	·34649
·06	·30	·0033401	·01619	·12726	·66	3·30	·095473	·12081	·34758
·07	·35	·0041958	·01880	·13712	·67	3·35	·097111	·12153	·34861
·08	·40	·0051102	·02133	·14623	·68	3·40	·098738	·12220	·34958
·09	·45	·0060784	·02393	·15472	·69	3·45	·10035	·12284	·35048
·10	·50	·0070963	·02646	·16268	·70	3·50	·10194	·12343	·35132
·11	·55	·0081607	·02896	·17059	·71	3·55	·10353	·12397	·35210
·12	·60	·0092682	·03144	·17731	·72	3·60	·10510	·12447	·35281
·13	·65	·010416	·03388	·18408	·73	3·65	·10665	·12493	·35345
·14	·70	·011602	·03630	·19054	·74	3·70	·10818	·12534	·35403
·15	·75	·012825	·03869	·19672	·75	3·75	·10969	·12570	·35454
·16	·80	·014081	·04106	·20264	·76	3·80	·11118	·12601	·35498
·17	·85	·015367	·04340	·20832	·77	3·85	·11266	·12627	·35535
·18	·90	·016690	·04571	·21380	·78	3·90	·11411	·12648	·35565
·19	·95	·018038	·04799	·21907	·79	3·95	·11553	·12664	·35587
·20	1·00	·019413	·05024	·22415	·80	4·00	·11693	·12674	·35601
·21	1·05	·020815	·05247	·22906	·81	4·05	·11831	·12682	·35607
·22	1·10	·022242	·05467	·23381	·82	4·10	·11966	·12677	·35606
·23	1·15	·023691	·05684	·23841	·83	4·15	·12098	·12670	·35595
·24	1·20	·025164	·05898	·24286	·84	4·20	·12227	·12656	·35576
·25	1·25	·026657	·06009	·24717	·85	4·25	·12352	·12636	·35547
·26	1·30	·028170	·06317	·25135	·86	4·30	·12475	·12608	·35508
·27	1·35	·029703	·06523	·25540	·87	4·35	·12593	·12573	·35459
·28	1·40	·031253	·06726	·25934	·88	4·40	·12708	·12530	·35398
·29	1·45	·032820	·06925	·26316	·89	4·45	·12819	·12507	·35325
·30	1·50	·034404	·07122	·26688	·90	4·50	·12925	·12418	·35239
·31	1·55	·036002	·07316	·27048	·91	4·55	·13027	·12347	·35138
·32	1·60	·037615	·07507	·27399	·92	4·60	·13124	·12265	·35021
·33	1·65	·039242	·07695	·27740	·93	4·65	·13215	·12171	·34887
·34	1·70	·040880	·07880	·28071	·94	4·70	·13301	·12061	·34730
·35	1·75	·042531	·08062	·28393	·95	4·75	·13380	·11937	·34550
·36	1·80	·044192	·08241	·28707	·96	4·80	·13452	·11787	·34333
·37	1·85	·045864	·08416	·29011	·97	4·85	·13516	·11612	·34077
·38	1·90	·047545	·08589	·29308	·98	4·90	·13570	·11391	·33758
·39	1·95	·049234	·08759	·29596	·989	4·945	·13608	·11141	·33379
·40	2·00	·050932	·08926	·29876	·990	4·950	·13612	·11107	·33325
·41	2·05	·052637	·09089	·30148	·991	4·955	·13615	·11076	·33281
·42	2·10	·054347	·09249	·30413	·992	4·960	·13618	·11033	·33216
·43	2·15	·056063	·09307	·30671	·993	4·965	·13621	·10999	·33164
·44	2·20	·057785	·09561	·30921	·994	4·970	·13624	·10948	·33089
·45	2·25	·059510	·09711	·31164	·995	4·975	·13627	·10901	·33017
·46	2·30	·061239	·09857	·31396	·996	4·980	·13629	·10849	·32938
·47	2·35	·062971	·10004	·31629	·997	4·985	·13631	·10790	·32848
·48	2·40	·064706	·10144	·31777	·998	4·990	·13633	·10720	·32742
·49	2·45	·066440	·10282	·31066	·999	4·995	·13634	·10427	·32290
·50	2·50	·068176	·10416	·32274	1·000	5·000	·13635	·10416	·32274

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·006	·000010	·00033	·01821	·51	3·06	·100674	·12657	·35577
·002	·012	·000029	·00066	·02578	·52	3·12	·103173	·12810	·35791
·003	·018	·000054	·00079	·02816	·53	3·18	·105670	·12958	·35997
·004	·024	·000084	·00133	·03648	·54	3·24	·108164	·13106	·36202
·005	·030	·000118	·00166	·04079	·55	3·30	·110654	·13244	·36392
·006	·036	·000154	·00199	·04467	·56	3·36	·113139	·13380	·36579
·007	·042	·000194	·00230	·04796	·57	3·42	·115617	·13512	·36759
·008	·048	·000238	·00265	·05154	·58	3·48	·118089	·13640	·36932
·009	·054	·000284	·00298	·05464	·59	3·54	·120553	·13763	·37098
·010	·060	·000332	·00331	·05769	·60	3·60	·123007	·13882	·37259
·011	·066	·000383	·00365	·06046	·61	3·66	·125451	·13996	·37411
·02	·12	·000937	·00675	·08240	·62	3·72	·127884	·14106	·37558
·03	·18	·001716	·00986	·09816	·63	3·78	·130304	·14211	·37697
·04	·24	·002634	·01305	·11425	·64	3·84	·132711	·14311	·37830
·05	·30	·003670	·01625	·12751	·65	3·90	·135104	·14407	·37957
·06	·36	·004809	·01943	·13941	·66	3·96	·137481	·14498	·38076
·07	·42	·006042	·02205	·14849	·67	4·02	·139841	·14584	·38189
·08	·48	·007359	·02566	·16019	·68	4·08	·142183	·14664	·38294
·09	·54	·008753	·02872	·16949	·69	4·14	·144505	·14740	·38393
·10	·60	·010219	·03175	·17821	·70	4·20	·146807	·14811	·38486
·11	·66	·011751	·03476	·18644	·71	4·26	·149087	·14877	·38571
·12	·72	·013346	·03772	·19423	·72	4·32	·151344	·14937	·38648
·13	·78	·014999	·04066	·20165	·73	4·38	·153577	·14991	·38719
·14	·84	·016708	·04356	·20872	·74	4·44	·155783	·15041	·38782
·15	·90	·018469	·04643	·21549	·75	4·50	·157963	·15084	·38838
·16	·96	·020278	·04927	·22198	·76	4·56	·160113	·15121	·38886
·17	1·02	·022134	·05086	·22560	·77	4·62	·162233	·15153	·38927
·18	1·08	·024034	·05485	·23420	·78	4·68	·164321	·15178	·38959
·19	1·14	·025975	·05759	·23998	·79	4·74	·166375	·15197	·38983
·20	1·20	·027956	·06029	·24555	·80	4·80	·168393	·15209	·38999
·21	1·26	·029974	·06296	·25093	·81	4·86	·170374	·15215	·39006
·22	1·32	·032028	·06560	·25613	·82	4·92	·172315	·15213	·39004
·23	1·38	·034116	·06820	·26116	·83	4·98	·174215	·15204	·38983
·24	1·44	·036236	·07077	·26604	·84	5·04	·176071	.15188	·38971
·25	1·50	·038386	·07348	·27107	·85	5·10	·177880	·15163	·38940
·26	1·56	·040566	·07581	·27534	·86	5·16	·179641	·15130	·38897
·27	1·62	·042772	·07828	·27978	·87	5·22	·181349	·15088	·38843
·28	1·68	·045005	·08071	·28409	·88	5·28	·183003	·15036	·38777
·29	1·74	·047262	·08310	·28828	·89	5·34	·184598	·14974	·38697
·30	1·80	·049542	·08547	·29235	·90	5·40	·186130	·14901	·38602
·31	1·86	·051844	·08779	·29630	·91	5·46	·187596	·14816	·38492
·32	1·92	·054166	·09008	·30014	·92	5·52	·188990	·14718	·38364
·33	1·98	·056508	·09234	·30388	·93	5·58	·190307	·14604	·38216
·34	2·04	·058868	·09456	·30750	·94	5·64	·191539	·14474	·38044
·35	2·10	·061245	·09674	·31103	·95	5·70	·192679	·14324	·37848
·36	2·16	·063638	·09889	·31447	·96	5·76	·193715	·14145	·37610
·37	2·22	·066044	·10100	·31781	·97	5·82	·194633	·13935	·37329
·38	2·28	·068465	·10307	·32101	·98	5·88	·195412	·13675	·36980
·39	2·34	·070898	·10511	·32421	·989	5·934	·195966	·13369	·36564
·40	2·40	·073342	·10711	·32728	·990	5.940	·196017	·13327	·36506
·41	2·46	·075797	·10907	·33026	·991	5·946	·196065	·13285	·36449
·42	2·52	·078260	·11099	·33316	·992	5·952	·196111	·13239	·36386
·43	2·58	·080732	·11288	·33598	·993	5·958	·196154	·13199	·36330
·44	2·64	·083211	·11473	·33872	·994	5·964	·196194	·13138	·36247
·45	2·70	·085695	·11654	·34138	·995	5·970	·196231	·13081	·36168
·46	2·76	·088185	·11829	·34393	·996	5·976	·196265	·13019	·36082
·47	2·82	·090679	·12005	·34648	·997	5·982	·196294	·12948	·35983
·48	2·88	·093176	·12173	·34890	·998	5·988	·196319	·12864	·35867
·49	2·94	·095675	·12338	·35126	·999	5·994	·196339	·12512	·35372
·50	3·00	·098174	·12500	·35355	1·000	6·000	·196349	·12500	·35355

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·007	·000014	·00038	·00196	·51	3·57	·13702	·14766	·38428
·002	·014	·000040	·00077	·02785	·52	3·64	·14043	·14945	·38659
·003	·021	·000074	·00092	·03042	·53	3·71	·14382	·15117	·38882
·004	·028	·000114	·00155	·03940	·54	3·78	·14722	·15290	·39103
·005	·035	·000160	·00194	·04406	·55	3·85	·15061	·15451	·39308
·006	·042	·000211	·00232	·04825	·56	3·92	·15399	·15610	·39510
·007	·049	·000265	·00268	·05180	·57	3·99	·15736	·15764	·39705
·008	·056	·000323	·00310	·05568	·58	4·06	·16073	·15913	·39892
·009	·063	·000386	·00348	·05902	·59	4·13	·16408	·16057	·40071
·010	·070	·000452	·00386	·06220	·60	4·20	·16742	·16196	·40245
·011	·077	·000521	·00425	·06523	·61	4·27	·17075	·16329	·40409
·02	·14	·001275	·00770	·08778	·62	4·34	·17406	·16459	·40567
·03	·21	·002336	·01150	·10725	·63	4·41	·17735	·16579	·40719
·04	·28	·003585	·01522	·12340	·64	4·48	·18063	·16696	·40862
·05	·35	·004995	·01896	·13772	·65	4·55	·18389	·16808	·40998
·06	·42	·006546	·02267	·15058	·66	4·62	·18712	·16914	·41127
·07	·49	·008223	·02632	·16225	·67	4·69	·19033	·17014	·41249
·08	·56	·010016	·02993	·17302	·68	4·76	·19352	·17108	·41363
·09	·63	·011913	·03351	·18307	·69	4·83	·19668	·17197	·41470
·10	·70	·013908	·03705	·19249	·70	4·90	·19982	·17280	·41569
·11	·77	·015995	·04055	·20138	·71	4·97	·20292	·17356	·41661
·12	·84	·018165	·04401	·20980	·72	5·04	·20599	·17426	·41745
·13	·91	·020416	·04745	·21783	·73	5·11	·20903	·17490	·41822
·14	·98	·022741	·05082	·22545	·74	5·18	·21203	·17588	·41938
·15	1·05	·025136	·05417	·23276	·75	5·25	·21500	·17598	·41950
·16	1·12	·027600	·05748	·23976	·76	5·32	·21793	·17642	·42002
·17	1·19	·030126	·06076	·24649	·77	5·39	·22081	·17678	·42046
·18	1·26	·032712	·06399	·25295	·78	5·46	·22365	·17708	·42081
·19	1·33	·035354	·06788	·25921	·79	5·53	·22645	·17730	·42107
·20	1·40	·038051	·07034	·26522	·80	5·60	·22920	·17744	·42124
·21	1·47	·040798	·07346	·27104	·81	5·67	·23189	·17751	·42132
·22	1·54	·043594	·07653	·27666	·82	5·74	·23454	·17749	·42129
·23	1·61	·046436	·07957	·28209	·83	5·81	·23712	·17738	·42117
·24	1·68	·049321	·08257	·28735	·84	5·88	·23965	·17719	·42094
·25	1·75	·052248	·08553	·29245	·85	5·95	·24211	·17690	·42060
·26	1·82	·055214	·08844	.29740	·86	6·02	·24451	·17651	·42014
·27	1·89	·058084	·09132	·30220	·87	6·09	·24683	·17602	·41955
·28	1·96	·061256	·09416	·30686	·88	6·16	·24908	·17542	·41884
·29	2·03	·064328	·09696	·31138	·89	6·23	·25125	·17470	·41797
·30	2·10	·067432	·09971	·31578	·90	6·30	·25334	·17385	·41696
·31	2·17	·070565	·10243	·32005	·91	6·37	·25533	·17286	·41577
·32	2·24	·073726	·10509	·32419	·92	6·44	·25723	·17171	·41439
·33	2·31	·076914	·10773	·32823	·93	6·51	·25902	·17039	·41279
·34	2·38	·080126	·11032	·33215	·94	6·58	·26010	·16886	·41093
·35	2·45	·083361	·11286	·33596	·95	6·65	·26225	·16712	·40880
·36	2·52	·086618	·11537	·33967	·96	6·72	·26366	·16503	·40624
·37	2·59	·089894	·11783	·34328	·97	6·79	·26491	·16257	·40320
·38	2·66	·093188	·12025	·34678	·98	6·86	·26597	·15955	·39943
·39	2·73	·096500	·12263	·35019	·989	6·923	·26673	·15598	·39494
·40	2·80	·099827	·12496	·35350	·990	6·930	·26680	·15548	·39431
·41	2·87	·10316	·12725	·35673	·991	6·937	·26686	·15499	·39370
·42	2·94	·10652	·12949	·35986	·992	6·944	·26692	·15446	·39302
·43	3·01	·10988	·13169	·36290	·993	6·951	·26698	·15398	·39241
·44	3·08	·11325	·13385	·36586	·994	6·958	·26704	·15328	·39151
·45	3·15	·11664	·13596	·36873	·995	6·965	·26709	·15261	·39066
·46	3·22	·12003	·13800	·37149	·996	6·972	·26713	·15189	·38973
·47	3·29	·12342	·14006	·37425	·997	6·679	·26717	·15106	·38866
·48	3·36	·12682	·14202	·37686	·998	6·986	·26721	·15008	·38740
·49	3·43	·13022	·14395	·37941	·999	6·993	·26723	·14597	·38207
·50	3·50	·13362	·14583	·38188	1·000	7·000	·26725	·14583	·38188

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·008	·000016	·00044	·02103	·51	[illegible]	·178976	·16876	·41100
·002	·016	·000042	·00088	·02977	·52	[illegible]	·183420	·17080	·41328
·003	·024	·000096	·00105	·03252	·53	4·24	·187856	·17277	·41567
·004	·032	·000148	·00177	·04213	·54	4·32	·192292	·17474	·41803
·005	·040	·000208	·00221	·04711	·55	4·40	·196716	·17659	·42023
·006	·048	·000272	·00266	·05158	·56	4·48	·201136	·17840	·42238
·007	·056	·000344	·00306	·05538	·57	4·56	·205540	·18016	·42446
·008	·064	·000424	·00354	·05952	·58	4·64	·209936	·18186	·42646
·009	·072	·000504	·00398	·06310	·59	4·72	·214316	·18351	·42838
·010	·080	·000588	·00422	·06550	·60	4·80	·218676	·18510	·43024
·011	·088	·000680	·00486	·06973	·61	4·88	·223024	·18662	·43199
·02	·16	·001664	·00880	·09384	·62	4·96	·227348	·18808	·43368
·03	·24	·003052	·01314	·11466	·63	5·04	·231652	·18948	·43530
·04	·32	·004684	·01740	·13192	·64	5·12	·235932	·19082	·43683
·05	·40	·006528	·02167	·14723	·65	5·20	·240192	·19210	·43829
·06	·48	·008548	·02591	·16098	·66	5·28	·244856	·19335	·43972
·07	·56	·010740	·03008	·17345	·67	5·36	·248696	·19445	·44097
·08	·64	·013080	·03421	·18497	·68	5·44	·252768	·19553	·44219
·09	·72	·015560	·03830	·19571	·69	5·52	·256888	·19654	·44334
·10	·80	·018168	·04234	·20578	·70	5·60	·260992	·19749	·44440
·11	·88	·020892	·04634	·21528	·71	5·68	·265044	·19836	·44537
·12	·96	·023728	·05030	·22429	·72	5·76	·269056	·19916	·44628
·13	1·04	·026664	·05421	·23285	·73	5·84	·273024	·19989	·44709
·14	1·12	·029704	·05809	·24102	·74	5·92	·276948	·20054	·44782
·15	1·20	·032832	·06191	·24883	·75	6·00	·280824	·20112	·44847
·16	1·28	·036048	·06723	·25929	·76	6·08	·284644	·20162	·44903
·17	1·36	·039348	·06944	·26352	·77	6·16	·288412	·20204	·44949
·18	1·44	·042728	·07313	·27040	·78	6·24	·292124	·20238	·44987
·19	1·52	·046176	·07678	·27710	·79	6·32	·295776	·20263	·45015
·20	1·60	·049700	·08039	·28354	·80	6·40	·299364	·20276	·45032
·21	1·68	·053288	·08395	·28975	·81	6·48	·302888	·20287	·45041
·22	1·76	·056940	·08747	·29576	·82	6·56	·306336	·20284	·45038
·23	1·84	·060608	·09094	·30157	·83	6·64	·309716	·20272	·45025
·24	1·92	·064420	·09437	·30719	·84	6·72	·313016	·20250	·45001
·25	2·00	·068244	·09775	·31265	·85	6·80	·316232	·20218	·44964
·26	2·08	·072116	·10108	·31794	·86	6·88	·319360	·20173	·44915
·27	2·16	·076040	·10437	·32307	·87	6·96	·322396	·20117	·44852
·28	2·24	·080008	·10771	·32804	·88	7·04	·325332	·20048	·44775
·29	2·32	·084020	·11081	·33288	·89	7·12	·328172	·19966	·44683
·30	2·40	·088072	·11396	·33758	·90	7·20	·330896	·19869	·44574
·31	2·48	·092168	·11706	·34215	·91	7·28	·333512	·19755	·44447
·32	2·56	·096296	·12011	·34658	·92	7·36	·335980	·19624	·44300
·33	2·64	·100460	·12312	·35089	·93	7·44	·338324	·19473	·44128
·34	2·72	·104656	·12608	·35508	·94	7·52	·340512	·19298	·43930
·35	2·80	·108880	·12899	·35916	·95	7·60	·342540	·19100	·43703
·36	2·88	·113132	·13185	·36312	·96	7·68	·344380	·18860	·43429
·37	2·96	·117412	·13467	·36697	·97	7·76	·346012	·18580	·43104
·38	3·04	·121716	·13743	·37072	·98	7·84	·347396	·18234	·42702
·39	3·12	·126040	·14015	·37437	·989	7·912	·348384	·17826	·42221
·40	3·20	·130384	·14282	·37791	·990	7·920	·348472	·17769	·42154
·41	3·28	·134748	·14543	·38136	·991	7·928	·348560	·17714	·42088
·42	3·36	·139128	·14800	·38471	·992	7·936	·348644	·17653	·42015
·43	3·44	·143524	·15051	·38796	·993	7·944	·348716	·17598	·41950
·44	3·52	·147928	·15297	·39112	·994	7·952	·348788	·17518	·41854
·45	3·60	·152348	·15539	·39419	·995	7·960	·348856	·17442	·41715
·46	3·68	·156776	·15772	·39714	·996	7·968	·348916	·17359	·41664
·47	3·76	·161208	·16007	·40009	·997	7·976	·348968	·17264	·41550
·48	3·84	·165644	·16231	·40288	·998	7·984	·349012	·17152	·41417
·49	3·92	·170088	·16451	·40561	·999	7·992	·349048	·17072	·41318
·50	4·00	·174532	·16666	·40825	1·000	8·000	·349064	·16666	·40825

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·009	·000018	·00049	·02230	·51	4·59	·226512	·18986	·43573
·002	·018	·000063	·00099	·03158	·52	4·68	·232137	·19215	·43835
·003	·027	.000117	·00119	·03450	·53	4·77	·237753	·19437	·44087
·004	·036	·000189	·00199	·04468	·54	4·86	·243369	·19659	·44338
·005	·045	·000261	·00249	·04996	·55	4·95	·248967	·19866	·44571
·006	·054	·000342	·00299	·05471	·56	5·04	·254556	·20070	·44800
·007	·063	·000432	·00345	·05874	·57	5·13	·260136	·20268	·45020
·008	·072	·000531	·00398	·06313	·58	5·22	·265698	·20460	·45232
·009	·081	·000639	·00447	·06693	·59	5·31	·271242	·20644	·45436
·010	·090	·000747	·00497	·07053	·60	5·40	·276768	·20824	·45633
·011	·099	·000864	·00547	·07396	·61	5·49	·281267	·20994	·45820
·02	·18	·002106	·00990	·09953	·62	5·58	·287739	·21159	·45999
·03	·27	·003861	·01479	·10863	·63	5·67	·293409	·21316	·46170
·04	·36	·005931	·01958	·13976	·64	5·76	·298602	·21467	·46333
·05	·45	·008253	·02438	·15615	·65	5·85	·303984	·21611	·46487
·06	·54	·010818	·02915	·17074	·66	5·94	·309330	·21747	·46634
·07	·63	·013590	·03384	·18397	·67	6·03	·314640	·21876	·46772
·08	·72	·016551	·03849	·19619	·68	6·12	·319914	·21997	·46901
·09	·81	·019692	·04309	·20758	·69	6·21	·325134	·22111	·47023
·10	·90	·022986	·04763	·21826	·70	6·30	·330318	·22217	·47135
·11	·99	·026433	·05214	·22831	·71	6·39	·335448	·22315	·47239
·12	1·08	·030024	·05659	·23789	·72	6·48	·340524	·22405	·47334
·13	1·17	·033741	·06099	·24597	·73	6·57	·345546	·22487	·47421
·14	1·26	·037593	·06386	·25564	·74	6·66	·350514	·22561	.47498
·15	1·35	·041553	·06965	·26392	·75	6·75	·355419	·22626	·47567
·16	1·44	·045621	·07391	·27187	·76	6·84	·360252	·22682	·47626
·17	1·53	·049797	·07812	·27950	·77	6·93	·365022	·22729	·47675
·18	1·62	·054072	·08227	·28684	·78	7·02	·369720	·22767	·47715
·19	1.71	·058446	·08638	·29391	·79	7·11	·374346	·22796	·47745
·20	1·80	·062901	·09044	·30073	·80	7·20	·379782	·22814	·47764
·21	1·89	·067437	·09445	·30732	.81	7·29	·383346	·22822	·47773
·22	1·98	·072063	·09840	·31369	·82	7.38	·387711	·22820	·47770
·23	2·07	·076761	·10231	·31986	·83	7·47	·391959	·22806	·47756
·24	2·16	·081531	·10616	·32583	·84	7·56	·396156	·22782	·47730
·25	2·25	·086364	·10996	·33161	·85	7·65	·400230	·22744	·47691
·26	2·34	·091269	·11372	·33722	·86	7·74	·404190	·22695	·47639
·27	2·43	·096237	·11742	·34266	·87	7·83	·408033	·22632	·47573
·28	2·52	·101259	·12106	·34794	·88	7·92	·411759	·22554	·47491
·29	2·61	·106335	·12466	·35307	·89	8·01	·415341	·22462	·47394
·30	2·70	·111465	·12820	·35805	·90	8·10	·418797	·22352	·47278
·31	2·79	·116649	·13199	·36289	·91	8·19	·422091	·22225	·47143
·32	2·88	·121869	·13513	·36760	·92	8·28	·425232	·22077	·46986
·33	2·97	·127143	·13851	·37217	·93	8·37	·428193	·21907	·46805
·34	3·06	·132453	·14184	·37662	·94	8·46	·430965	·21711	·46595
·35	3·15	·137799	·14511	·38094	·95	8·55	·433521	·21487	·46354
·36	3·24	·143181	·14834	·38514	·96	8·64	·435861	·21218	·46063
·37	3·33	·148599	·15150	·38923	·97	8·73	·437922	·20902	·45719
·38	3·42	·154044	·15462	·39321	·98	8·82	·439677	·20466	·45291
·39	3·51	·159516	·15766	·39707	·989	8·901	·440919	·20054	·44782
·40	3·60	·165015	·16067	·40084	·990	8·910	·441036	·19991	·44711
·41	3·69	·170541	·16361	·40449	·991	8·919	·441144	·19928	·44641
·42	3·78	·176085	·16649	·40804	·992	8·928	·441252	·19859	·44564
·43	3·87	·181647	·16832	·41149	·993	8·937	·441351	·19798	·44495
·44	3·96	·187218	·17210	·41484	·994	8·946	·441441	·19708	·44393
·45	4·05	·192687	·17481	·41810	·995	8·955	·441522	·19622	·44292
·46	4·14	·198414	·17743	·42123	·996	8·964	·441594	·19528	·44191
·47	4·23	·205021	·18008	·42435	·997	8·973	·441657	·19422	·44070
·48	4·32	·209646	·18260	·42732	·998	8·982	·441711	·19296	·43928
·49	4·41	·215271	·18508	·43021	·999	8·991	·441756	·18768	·43322
·50	4·50	·220893	·18750	·43301	1·000	9·000	·441786	·18750	·43301

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·01	·000028	·00055	·02351	·51	5·1	·27965	·21095	·45930
·002	·02	·000082	·00110	·03329	·52	5·2	·28659	·21351	·46206
·003	·03	·000152	·00132	·03636	·53	5·3	·29352	·21597	·46526
·004	·04	·000234	·00221	·04710	·54	5·4	·30045	·21843	·46736
·005	·05	·000326	·00277	·05267	·55	5·5	·30736	·22073	·46982
·006	·06	·000429	·00332	·05767	·56	5·6	·31427	·22301	·47224
·007	·07	·000540	·00383	·06191	·57	5·7	·32115	·22521	·47456
·008	·08	·000660	·00442	·06655	·58	5·8	·32802	·22733	·47680
·009	·09	·000788	·00497	·07055	·59	5·9	·33486	·22939	·47894
·010	·10	·000922	·00552	·07435	·60	6·0	·34168	·23138	·48102
·011	·11	·001064	·00607	·07796	·61	6·1	·34848	·23327	·48299
·02	·2	·002603	·01100	·10492	·62	6·2	·35523	·23510	·48487
·03	·3	·004768	·01643	·12819	·63	6·3	·36195	·23685	·48668
·04	·4	·007318	·02175	·14750	·64	6·4	·36864	·23858	·48839
·05	·5	·010194	·02709	·16462	·65	6·5	·37528	·24012	·49002
·06	·6	·013360	·03239	·17998	·66	6·6	·38189	·24164	·49156
·07	·7	·016783	·03760	·19392	·67	6·7	·38844	·24307	·49302
·08	·8	·020440	·04277	·20681	·68	6·8	·39495	·24441	·49438
·09	·9	·024313	·04787	·21881	·69	6·9	·40140	·24568	·49566
·10	1·0	·028385	·05294	·23010	·70	7·0	·40776	·24686	·49685
·11	1·1	·032642	·05793	·24069	·71	7·1	·41412	·24795	·49795
·12	1·2	·037072	·06288	·25076	·72	7·2	·42040	·24895	·49895
·13	1·3	·041664	·06777	·26033	·73	7·3	·42660	·24990	·49987
·14	1·4	·046408	·07261	·26947	·74	7·4	·43272	·25068	·50068
·15	1·5	·051300	·07739	·27820	·75	7·5	·43876	·25140	·50140
·16	1·6	·056324	·08212	·28658	·76	7·6	·44472	·25203	·50202
·17	1·7	·061468	·08680	·29462	·77	7·7	·45064	·25255	·50255
·18	1·8	·066760	·09142	·30236	·78	7·8	·45644	·25297	·50296
·19	1·9	·072152	·09598	·30982	·79	7·9	·46212	·25329	·50328
·20	2·0	·077652	·10049	·31701	·80	8·0	·46772	·25349	·50348
·21	2·1	·083260	·10494	·32395	·81	8·1	·47324	·25358	·50357
·22	2·2	·088968	·10934	·33067	·82	8·2	·47864	·25355	·50354
·23	2·3	·094764	·11368	·33717	·83	8·3	·48392	·25341	·50340
·24	2·4	·100656	·11796	·34346	·84	8·4	·48908	·25313	·50312
·25	2·5	·106628	·12218	·34955	·85	8·5	·49408	·25272	·50271
·26	2·6	·112680	·12635	·35547	·86	8·6	·49900	·25217	·50152
·27	2·7	·118812	·13044	·36116	·87	8·7	·50372	·25146	·50147
·28	2·8	·125012	·13452	·36677	·88	8·8	·50832	·25061	·50061
·29	2·9	·131280	·13851	·37217	·89	8·9	·51276	·24958	·49958
·30	3·0	·137616	·14245	·37743	·90	9·0	·51700	·24836	·49836
·31	3·1	·144008	·14633	·38253	·91	9·1	·52108	·24695	·49694
·32	3·2	·150460	·15014	·38749	·92	9·2	·52496	·24531	·49529
·33	3·3	·156968	·15390	·39231	·93	9·3	·52860	·24341	·49337
·34	3·4	·163520	·15760	·39699	·94	9·4	·53204	·24123	·49115
·35	3·5	·170124	·16124	·40155	·95	9·5	·53520	·23875	·48862
·36	3·6	·176768	·16482	·40598	·96	9·6	·53808	·23575	·48555
·37	3·7	·183456	·16834	·41029	·97	9·7	·54064	·23225	·48192
·38	3·8	·190180	·17179	·41448	·98	9·8	·54280	·22793	·47741
·39	3·9	·196936	·17199	·41856	·989	9·89	·54432	·22283	·47205
·40	4·0	·203728	·17852	·42253	·990	9·90	·54448	·22213	·47130
·41	4·1	·210548	·18174	·42637	·991	9·91	·54460	·22142	·47056
·42	4·2	·217388	·18500	·43012	·992	9·92	·54472	·22066	·46975
·43	4·3	·224252	·18814	·43376	·993	9·93	·54484	·21998	·46902
·44	4·4	·231140	·19122	·43729	·994	9·94	·54496	·21898	·46797
·45	4·5	·238040	·19424	·44072	·995	9·95	·54508	·21802	·46693
·46	4·6	·244956	·19715	·44402	·996	9·96	·54516	·21699	·46582
·47	4·7	·251884	·20009	·44731	·997	9·97	·54524	·21580	·46454
·48	4·8	·258824	·20289	·45044	·998	9·98	·54532	·21441	·45774
·49	4·9	·265760	·20565	·45349	·999	9·99	·54536	·20854	·45666
·50	5·0	·272704	·20833	·45643	1·000	10·00	·54540	·20833	·45643

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·011	·000035	·00060	·02466	·51	5·61	·33837	·23205	·48172
·002	·022	·000099	·00121	·03491	·52	5·72	·34677	·23485	·48481
·003	·033	·000184	·00145	·03814	·53	5·83	·35516	·23756	·48741
·004	·044	·000283	·00244	·04940	·54	5·94	·36355	·24028	·49018
·005	·055	·000395	·00305	·05524	·55	5·05	·37191	·24281	·49276
·006	·066	·000520	·00365	·06049	·56	6·16	·38027	·24531	·49528
·007	·077	·000654	·00421	·06494	·57	6·27	·38860	·24773	·49772
·008	·088	·000798	·00487	·06979	·58	6·38	·39691	·25007	·50007
·009	·099	·000953	·00547	·07399	·59	6·49	·40519	·25233	·50232
·010	·110	·001116	·00608	·07798	·60	6·60	·41344	·25452	·50450
·011	·121	·001288	·00668	·09175	·61	6·71	·42165	·25660	·50656
·02	·22	·003150	·01211	·11004	·62	6·82	·42983	·25861	·50854
·03	·33	·005769	·01807	·13445	·63	6·93	·43796	·26054	·51043
·04	·44	·008854	·02393	·15470	·64	7·04	·44605	·26238	·51223
·05	·55	·012336	·02980	·17265	·65	7·15	·45410	·26413	·51372
·06	·66	·016166	·03563	·18877	·66	7·26	·46208	·26580	·51556
·07	·77	·020307	·04136	·20339	·67	7·37	·47002	·26738	·51708
·08	·88	·024733	·04704	·21690	·68	7·48	·47789	·26885	·51829
·09	·99	·029419	·05266	·22949	·69	7·59	·48458	·27025	·51986
·10	1·10	·034346	·05822	·24130	·70	7·70	·49343	·27155	·52110
·11	1·21	·039498	·06372	·25244	·71	7·81	·50110	·27275	·52226
·12	1·32	·044858	·06916	·26300	·72	7·92	·50870	·27385	·52331
·13	1·43	·050415	·07455	·27304	·73	8·03	·51619	·27485	·52426
·14	1·54	·056158	·07987	·28262	·74	8·14	·52360	·27575	·52512
·15	1·65	·062075	·08513	·29178	·75	8·25	·53093	·27654	·52588
·16	1·76	·068156	·09033	·30056	·76	8·36	·53815	·27723	·52653
·17	1·87	·074394	·09548	·30900	·77	8·47	·54528	·27781	·52708
·18	1·98	·080780	·10056	·31712	·78	8·58	·55230	·27827	·52751
·19	2·09	·087304	·10557	·32494	·79	8·69	·55920	·27862	·52784
·20	2·20	·093963	·11054	·33248	·80	8·80	·56598	·27884	·52805
·21	2·31	·10074	·11544	·33976	·81	8·90	·57264	·27894	·52815
·22	2·42	·10765	·12027	·34680	·82	9·02	·57917	·27891	·52812
·23	2·53	·11466	·12505	·35362	·83	9·13	·58555	·27875	·62797
·24	2·64	·12179	·12976	·36022	·84	9·24	·59179	·27845	·52768
·25	2·75	·12902	·13441	·36662	·85	9·35	·59787	·27799	·52725
·26	2·86	·13634	·13902	·37286	·86	9·46	·60379	·27738	·52668
·27	2·97	·14376	·14351	·37883	·87	9·57	·60953	·27662	·52594
·28	3·08	·15126	·14797	·38467	·88	9·68	·61509	·27567	·52504
·29	3·19	·15885	·15236	·39034	·89	9·79	·62045	·27454	·52397
·30	3·30	·16651	·15669	·39584	·90	9·90	·62546	·27320	·52269
·31	3·41	·17425	·16096	·40120	·91	10·01	·63053	·27164	·52119
·32	3·52	·18205	·16512	·40640	·92	10·12	·63521	·26984	·51946
·33	3·63	·18993	·16929	·41146	·93	10·23	·63964	·26776	·51746
·34	3·74	·19786	·17336	·41637	·94	10·34	·64378	·26536	·51513
·35	3·85	·20585	·17737	·42115	·95	10·45	·64761	·26262	·51247
·36	3·96	·21389	·18130	·42562	·96	10·56	·65109	·25934	·50925
·37	4·07	·22198	·18517	·43031	·97	10·67	·65418	·25548	·50545
·38	4·18	·23011	·18897	·43471	·98	10·78	·65680	·25072	·50072
·39	4·29	·23829	·19271	·43899	·989	10·879	·65866	·24512	·49509
·40	4·40	·24651	·19638	·44314	·990	10·890	·65883	·24433	·49436
·41	4·51	·25476	·19997	·44718	·991	10·901	·65899	·24357	·49353
·42	4·62	·26304	·20350	·45111	·992	10·912	·65915	·24273	·49268
·43	4·73	·27134	·20696	·45492	·993	10·923	·65929	·24198	·49192
·44	4·84	·27968	·21034	·45863	·994	10·934	·65943	·24087	·49079
·45	4·95	·28803	·21366	·46223	·995	10·945	·65955	·23983	·48972
·46	5·06	·29640	·21687	·46569	·996	10·956	·65966	·23868	·48855
·47	5·17	·30478	·22010	·46914	·997	10·967	·65976	·23738	·48722
·48	5·28	·31317	·22318	·47243	·998	10·978	·65985	·23585	·48564
·49	5·39	·32157	·22621	·47561	·999	10·989	·65991	·22939	·47895
·50	5·50	·32997	·22917	·47871	1·000	11·000	·65995	·22917	·47871

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·012	·000042	·00066	·02575	·51	6·12	·402698	·25314	·50313
·002	·024	·000119	·00133	·03646	·52	6·24	·412694	·25620	·50616
·003	·036	·000219	·00158	·03983	·53	6·36	·422681	·25916	·50908
·004	·048	·000317	·00266	·05159	·54	6·48	·432656	·26212	·51197
·005	·060	·000471	·00332	·05769	·55	6·60	·442615	·26488	·51467
·006	·072	·000619	·00399	·06317	·56	6·72	·452555	·26761	·51731
·007	·084	·000779	·00460	·06782	·57	6·84	·462470	·27025	·51985
·008	·096	·000952	·00531	·07290	·58	6·96	·472356	·27280	·52230
·009	·108	·001135	·00597	·07728	·59	7·08	·482211	·27536	·52466
·010	·120	·001329	·00663	·08144	·60	7·20	·492028	·27765	·52693
·011	·132	·001533	·00729	·08540	·61	7·32	·501805	·27992	·52908
·02	·24	·003749	·01321	·11493	·62	7·44	·511537	·28222	·53115
·03	·36	·006866	·01972	·14042	·63	7·56	·521219	·28422	·53312
·04	·48	·010538	·02610	·16157	·64	7·68	·530847	·28623	·53500
·05	·60	·014681	·03251	·18032	·65	7·80	·540418	·28814	·53679
·06	·72	·019239	·03887	·19715	·66	7·92	·549925	·28996	·53848
·07	·84	·024168	·04512	·21243	·67	8·04	·559364	·29168	·54007
·08	·96	·029435	·05132	·22654	·68	8·16	·568732	·29327	·54156
·09	1·08	·035012	·05745	·23969	·69	8·28	·578022	·29481	·54297
·10	1·20	·040875	·06351	·25203	·70	8·40	·587230	·29623	·54427
·11	1·32	·047006	·06952	·26367	·71	8·52	·596350	·29754	·54547
·12	1·44	·053385	·07545	·27469	·72	8·64	·605378	·29874	·54657
·13	1·56	·059999	·08132	·28518	·73	8·76	·614308	·29983	·54757
·14	1·68	·066833	·08713	·29518	·74	8·88	·623135	·30082	·54847
·15	1·80	·073875	·09287	·30475	·75	9·00	·631852	·30168	·54926
·16	1·92	·081112	·09855	·31393	·76	9·12	·640453	·30243	·54994
·17	2·04	·088536	·10416	·32274	·77	9·24	·648933	·30306	·55051
·18	2·16	·096135	·10970	·33121	·78	9·36	·657284	·30356	·55097
·19	2·28	·103900	·11518	·33938	·79	9·48	·665500	·30394	·55131
·20	2·40	·111824	·12059	·34726	·80	9·60	·673574	·30419	·55153
·21	2·52	·119898	·12593	·35487	·81	9·72	·681498	·30430	·55163
·22	2·64	·128114	·13120	·36222	·82	9·84	·689263	·30427	·55160
·23	2·76	·136465	·13641	·36934	·83	9·96	·696862	·30409	·55144
·24	2·88	·144945	·14155	·37423	·84	10·08	·704286	·30376	·55114
·25	3·00	·153546	·14662	·38291	·85	10·20	·711523	·30326	·55069
·26	3·12	·162263	·15162	·38939	·86	10·32	·718565	·30260	·55009
·27	3·24	·171090	·15656	·39567	·87	10·44	·725399	·30176	·54932
·28	3·36	·180020	·16142	·40177	·88	10·56	·732013	·30073	·54838
·29	3·48	·189048	·16621	·40769	·89	10·68	·738392	·29949	·54726
·30	3·60	·198168	·17094	·41344	·90	10·80	·744523	·29803	·54592
·31	3·72	·207376	·17599	·41904	·91	10·92	·750386	·29633	·54436
·32	3·84	·216666	·18017	·42447	·92	11·04	·755963	·29436	·54255
·33	3·96	·226634	·18468	·42975	·93	11·16	·761230	·29209	·54046
·34	4·08	·235473	·18912	·43488	·94	11·28	·766159	·28948	·53803
·35	4·20	·244980	·19349	·43987	·95	11·40	·770717	·28649	·53525
·36	4·32	·254551	·19778	·44473	·96	11·52	·774860	·28291	·53189
·37	4·44	·264179	·20200	·44945	·97	11·64	·778532	·27870	·52792
·38	4·56	·273861	·20615	·45404	·98	11·76	·781649	·27351	·52298
·39	4·68	·283593	·21022	·45850	·989	11·868	·783865	·26739	·51710
·40	4·80	·293370	·21423	·46285	·990	11·880	·784069	·26654	·51628
·41	4·92	·303187	·21815	·46706	·991	11·892	·784263	·26571	·51547
·42	5·04	·313042	·22199	·47116	·992	11·904	·784446	·26479	·51458
·43	5·16	·322928	·22577	·47515	·993	11·916	·784619	·26397	·51378
·44	5·28	·332843	·22946	·47902	·994	11·928	·784779	·26277	·51261
·45	5·40	·342783	·23308	·48279	·995	11·940	·784927	·26163	·51150
·46	5·52	·352742	·23658	·48639	·996	11·952	·785061	·26038	·51027
·47	5·64	·362717	·24010	·49000	·997	11·964	·785179	·25896	·50888
·48	5·76	·372704	·24347	·49342	·998	11·976	·785279	·25728	·50723
·49	5·88	·382700	·24677	·49676	·999	11·988	·785356	·25024	·50024
·50	6·00	·392699	·25000	·50000	1·000	12·000	·785398	·25000	·50000

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·015	·000064	·00082	·02879	·51	7·65	·629217	·31643	·56252
·002	·030	·000185	·00166	·04077	·52	7·80	·644832	·32025	·56591
·003	·045	·000342	·00198	·04454	·53	7·95	·660438	·32395	·56917
·004	·060	·000526	·00332	·05768	·54	8·10	·676017	·32765	·57240
·005	·075	·000735	·00416	·06450	·55	8·25	·691578	·33110	·57542
·006	·090	·000966	·00498	·07063	·56	8·40	·707112	·33451	·57837
·007	·105	·001216	·00575	·07583	·57	8·55	·722601	·33781	·58121
·008	·120	·001486	·00664	·08150	·58	8·70	·738054	·34101	·58396
·009	·135	·001773	·00746	·08640	·59	8·85	·753453	·34408	·58659
·010	·150	·002076	·00829	·09106	·60	9·00	·768789	·34707	·58913
·011	·165	·002394	·00911	·09549	·61	9·15	·784080	·34991	·59153
·02	·30	·005857	·01651	·12850	·62	9·30	·799272	·35265	·59385
·03	·45	·010728	·02465	·15700	·63	9·45	·814401	·35528	·59605
·04	·60	·016465	·03263	·18065	·64	9·60	·829440	·35779	·59816
·05	·75	·022938	·04064	·20161	·65	9·75	·844398	·36018	·60085
·06	·90	·030060	·04859	·22043	·66	9·90	·859257	·36245	·60204
·07	1·05	·037762	·05641	·23751	·67	10·05	·873999	·36460	·60382
·08	1·20	·045991	·06415	·25329	·68	10·20	·888642	·36662	·60549
·09	1·35	·054705	·07181	·26799	·69	10·35	·90315	·36852	·60706
·10	1·50	·063866	·07939	·28179	·70	10·50	·91746	·37029	·60852
·11	1·65	·073446	·08690	·29479	·71	10·65	·93177	·37193	·60986
·12	1·80	·083413	·09432	·30712	·72	10·80	·94590	·37343	·61109
·13	1·95	·093744	·10166	·31884	·73	10·95	·95985	·37480	·61220
·14	2·10	·104418	·11145	·33381	·74	11·10	·97362	·37602	·61321
·15	2·25	·115425	·11612	·34073	·75	11·25	·98721	·37711	·61409
·16	2·40	·116729	·12319	·35098	·76	11·40	1·00062	·37805	·61485
·17	2·55	·138303	·13020	·36084	·77	11·55	1·01394	·37883	·61549
·18	2·70	·150210	·13713	·37031	·78	11·70	1·01699	·37946	·61600
·19	2·85	·162342	·14397	·37944	·79	11·85	1·03977	·37993	·61639
·20	3·00	·174717	·15074	·38825	·80	12·00	1·05237	·38024	·61663
·21	3·15	·187335	·15742	·39676	·81	12·15	1·06479	·38038	·61675
·22	3·30	·200178	·16401	·40498	·82	12·30	1·07694	·38034	·61672
·23	3·45	·213219	·17052	·40540	·83	12·45	1·08882	·38011	·61653
·24	3·60	·226476	·17694	·42064	·84	12·60	1·10043	·37970	·61620
·25	3·75	·239913	·18328	·42811	·85	12·75	1·11168	·37908	·61570
·26	3·90	·253530	·18953	·43536	·86	12·90	1·12275	·37825	·61502
·27	4·05	·267327	·19570	·44238	·87	13·05	1·13337	·37720	·61417
·28	4·20	·281277	·20178	·44920	·88	13·20	1·14372	·37591	·61312
·29	4·35	·295380	·20777	·45582	·89	13·35	1·15371	·37436	·61185
·30	4·50	·309636	·21367	·46225	·90	13·50	1·16325	·37254	·61036
·31	4·65	·324018	·21949	·46851	·91	13·65	1·17243	·37041	·60862
·32	4·80	·338535	·22522	·47457	·92	13·80	1·18116	·36798	·60660
·33	4·95	·353178	·23086	·48048	·93	13·95	1·18935	·36513	·60426
·34	5·10	·367920	·23640	·48627	·94	14·10	1·19709	·36185	·60154
·35	5·25	·382779	·24186	·49180	·95	14·25	1·20420	·35812	·59843
·36	5·40	·397728	·24723	·49723	·96	14·40	1·21068	·35364	·59468
·37	5·55	·412776	·25251	·50250	·97	14·55	1·21644	·34837	·59023
·38	5·70	·427905	·25769	·50763	·98	14·70	1·22130	·34190	·58472
·39	5·85	·443106	·26278	·51262	·989	14·835	1·22472	·33425	·57814
·40	6·00	·458388	·26779	·51653	·990	14·850	1·22508	·33318	·57722
·41	6·15	·473733	·27269	·52220	·991	14·865	1·22535	·33213	·57631
·42	6·30	·489123	·27750	·52678	·992	14·880	1·22562	·33099	·57518
·43	6·45	·504567	·28221	·53123	·993	14·895	1·22589	·32998	·57443
·44	6·60	·520065	·28683	·53557	·994	14·910	1·22616	·32847	·57312
·45	6·75	·535590	·29135	·53978	·995	14·925	1·22623	·32704	·57187
·46	6·90	·551151	·29573	·54381	·996	14·940	1·22661	·32548	·57051
·47	7·05	·566739	·30013	·54784	·997	14·955	1·22679	·32371	·56895
·48	7·20	·582354	·30434	·55167	·998	14·970	1·22697	·32161	·56711
·49	7·35	·597960	·30847	·55540	·999	14·985	1·22706	·31281	·55930
·50	7·50	·613584	·31250	·55902	1·000	15·000	1·22715	·31250	·55902

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·018	·000072	·000995	·031547	·51	9·18	·906048	·37972	·61621
·002	·036	·000252	·001995	·044665	·52	9·36	·928548	·38430	·61992
·003	·054	·000468	·002380	·048793	·53	9·54	·951012	·38874	·62349
·004	·072	·000756	·003993	·063195	·54	9·72	·973476	·39318	·62704
·005	·090	·001044	·004993	·070667	·55	9·90	·995868	·39732	·63034
·006	·108	·001368	·005987	·077377	·56	10·08	1·018224	·40141	·63357
·007	·126	·001728	·006901	·083073	·57	10·26	1·040544	·40537	·63669
·008	·144	·002124	·007972	·089286	·58	10·44	1·062792	·40920	·63969
·009	·162	·002556	·008959	·094654	·59	10·62	1·084968	·41290	·64257
·010	·180	·002988	·009950	·099754	·60	10·80	1·107072	·41649	·64536
·011	·198	·003456	·01094	·10460	·61	10·98	1·125068	·41989	·64799
·02	·36	·008424	·01981	·14076	·62	11·16	1·150956	·42318	·65052
·03	·54	·015444	·02958	·17199	·63	11·34	1·173636	·42633	·65294
·04	·72	·023724	·03916	·19789	·64	11·52	1·194408	·42935	·65524
·05	·90	·033012	·04877	·22085	·65	11·70	1·215936	·43222	·65743
·06	1·08	·043272	·05830	·24202	·66	11·88	1·237320	·43494	·65950
·07	1·26	·054360	·06769	·26018	·67	12·06	1·258560	·43752	·66145
·08	1·44	·066204	·07698	·27746	·68	12·24	1·279656	·43994	·66328
·09	1·62	·078768	·08618	·29356	·69	12·42	1·300536	·44222	·66500
·10	1·80	·091944	·09527	·30867	·70	12·60	1·321272	·44370	·66659
·11	1·98	·105732	·10428	·32292	·71	12·78	1·341792	·44631	·66806
·12	2·16	·120096	·11318	·33643	·72	12·96	1·362096	·44811	·66941
·13	2·34	·134964	·12199	·34927	·73	13·14	1·382184	·44975	·67064
·14	2·52	·150372	·13070	·36153	·74	13·32	1·402056	·45123	·67173
·15	2·70	·166212	·13931	·37325	·75	13·50	1·421676	·45253	·67270
·16	2·88	·182484	·14782	·38448	·76	13·68	1·441008	·45365	·67353
·17	3·06	·199188	·15660	·39446	·77	13·86	1·460088	·45459	·67423
·18	3·24	·216288	·16455	·40565	·78	14·04	1·478880	·45535	·67480
·19	3·42	·233784	·17277	·41566	·79	14·22	1·497384	·45592	·67522
·20	3·60	·251604	·18088	·42531	·80	14·40	1·519128	·45628	·67549
·21	3·78	·269748	·18890	·43462	·81	14·58	1·533384	·45645	·67561
·22	3·98	·288252	·19681	·44363	·82	14·76	1·550844	·45640	·67557
·23	4·14	·307044	·20462	·45235	·83	14·94	1·567836	·45613	·67538
·24	4·32	·326124	·21282	·46079	·84	15·12	1·584612	·45564	·67501
·25	4·50	·345456	·21993	·46898	·85	15·30	1·600920	·45490	·67446
·26	4·68	·365076	·22744	·47690	·86	15·48	1·616760	·45390	·67372
·27	4·86	·384948	·23484	·48460	·87	15·66	1·632132	·45264	·67278
·28	5·04	·405036	·24213	·49207	·88	15·84	1·647036	·45109	·67163
·29	5·22	·425340	·24932	·49932	·89	16·02	1·661364	·44924	·67025
·30	5·40	·445860	·25641	·50637	·90	16·20	1·675188	·44705	·66862
·31	5·58	·466596	·26339	·51321	·91	16·38	1·688364	·44450	·66671
·32	5·76	·487476	·27026	·51986	·92	16·56	1·700928	·44155	·66449
·33	5·94	·508572	·27703	·52633	·93	16·74	1.712772	·43814	·66192
·34	6·12	·529812	·28368	·53262	·94	16·92	1·723860	·43422	·65895
·35	6·30	·551196	·29024	·53873	·95	17·10	1·734084	·42974	·65555
·36	6·48	·572724	·29668	·54468	·96	17·28	1·743444	·42436	·65143
·37	6·66	·594396	·30301	·55046	·97	17·46	1·751688	·41805	·64657
·38	6·84	·616176	·30923	·55608	·98	17·64	1·758708	·41027	·64052
·39	7·02	·638064	·31534	·56155	·989	17·802	1·763676	·40109	·63332
·40	7·20	·660060	·32134	·56687	·990	17·820	1·764144	·39982	·63231
·41	7·38	·682164	·32722	·57203	·991	17·838	1·764576	·39856	·63132
·42	7·56	·704340	·33299	·57706	·992	17·856	1·765008	·39719	·63023
·43	7·74	·726588	·33865	·58194	·993	17·874	1·765404	·39596	·62926
·44	7·92	·748872	·34420	·58668	·994	17·892	1·765764	·39416	·62782
·45	8·10	·770748	·34963	·59129	·995	17·910	1·766088	·39244	·62645
·46	8·28	·793656	·35487	·59571	·996	17·928	1·766376	·39057	·62496
·47	8·46	·820084	·36016	·60016	·997	17·946	1·766628	·38844	·62325
·48	8·64	·838584	·36520	·60432	·998	17·964	1·766844	·38593	·62123
·49	8·82	·861084	·37016	·60841	·999	17·982	1·767024	·37537	·61267
·50	9·00	·883572	·37500	·61237	1·000	18·000	1·767144	·37500	·61237

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·021	·000129	·001161	·03405	·51	10·71	1·23326	·44299	·66558
·002	·042	·000364	·002327	·04824	·52	10·92	1·26387	·43804	·66185
·003	·063	·000671	·002777	·05270	·53	11·13	1·29145	·45353	·67345
·004	·084	·001032	·004659	·06825	·54	11·34	1·32508	·45871	·67728
·005	·105	·001442	·005826	·07633	·55	11·55	1·35558	·46247	·68021
·006	·126	·001893	·006985	·08358	·56	11·76	1·38594	·46831	·68433
·007	·147	·002386	·008052	·08973	·57	11·97	1·41631	·47293	·68771
·008	·168	·002915	·009301	·09644	·58	12·18	1·44992	·47740	·69094
·009	·189	·003476	·010428	·10247	·59	12·39	1·47677	·48189	·69418
·010	·210	·004071	·011609	·10774	·60	12·60	1·50683	·48589	·69706
·011	·231	·004695	·012765	·11298	·61	12·81	1·53677	·48987	·69991
·02	·42	·011481	·023117	·15204	·62	13·02	1·56659	·49389	·70277
·03	·63	·021027	·034510	·18577	·63	13·23	1·59623	·49739	·70526
·04	·84	·032272	·045687	·21423	·64	13·44	1·62571	·50090	·70774
·05	1·05	·044960	·056907	·23855	·65	13·65	1·65503	·50426	·71011
·06	1·26	·058783	·068025	·26081	·66	13·86	1·68410	·50743	·71234
·07	1·47	·074014	·078976	·28167	·67	14·07	1·71305	·51044	·71445
·08	1·68	·090144	·089817	·29969	·68	14·28	1·74174	·51326	·71642
·09	1·89	·10724	·10054	·31708	·69	14·49	1·77020	·51228	·71828
·10	2·00	·12518	·11115	·33340	·70	14·70	1·79839	·51841	·72000
·11	2·21	·14395	·12166	·34880	·71	14·91	1·82632	·52070	·72159
·12	2·52	·16349	·13205	·36338	·72	15·12	1·84970	·52280	·72305
·13	2·72	·18374	·14232	·37726	·73	15·33	1·88131	·52471	·72437
·14	2·94	·20467	·15248	·39049	·74	15·54	1·91274	·52643	·72555
·15	3·15	·22624	·16253	·40315	·75	15·75	1·93504	·52795	·72660
·16	3·36	·24840	·17246	·41529	·76	15·96	1·96183	·52926	·72750
·17	3·57	·27114	·18228	·42694	·77	16·17	1·98735	·53036	·72826
·18	3·78	·29441	·19198	·43816	·78	16·38	2·01293	·53125	·72870
·19	3·99	·31819	·20156	·44896	·79	16·59	2·03656	·53191	·72932
·20	4·20	·34246	·21054	·45885	·80	16·80	2·06282	·53232	·72960
·21	4·41	·36718	·22038	·46944	·81	17·01	2·08708	·53252	·72974
·22	4·62	·39234	·22962	·47944	·82	17·22	2·11086	·53247	·73970
·23	4·83	·41696	·23872	·48860	·83	17·43	2·13409	·53216	·73033
·24	5·04	·44388	·24772	·49771	·84	17·64	2·15689	·53158	·72909
·25	5·25	·47024	·25659	·50655	·85	17·85	2·17906	·53071	·72850
·26	5·46	·49693	·26534	·51511	·86	18·06	2·20060	·52955	·72770
·27	5·67	·51275	·27398	·52342	·87	18·27	2·22153	·52808	·72669
·28	5·88	·55131	·28249	·53149	·88	18·48	2·24178	·52627	·72545
·29	6·09	·57895	·29087	·53932	·89	18·69	2·26132	·52411	·72395
·30	6·30	·60688	·29914	·54694	·90	18·90	2·28009	·52156	·72219
·31	6·51	·63507	·30799	·55497	·91	19·11	2·29805	·51858	·72013
·32	6·72	·66353	·31603	·56217	·92	19·32	2·31513	·51514	·71773
·33	6·93	·69222	·32320	·56850	·93	19·53	2·33126	·51117	·71496
·34	7·14	·72113	·33020	·57529	·94	19·74	2·34630	·50659	·71175
·35	7·35	·74852	·33860	·58190	·95	19·95	2·36031	·50138	·70808
·36	7·56	·77956	·34612	·58832	·96	20·16	2·37300	·49509	·70362
·37	7·77	·80904	·35351	·59456	·97	20·37	2·38425	·48772	·69837
·38	7·98	·83871	·36076	·60064	·98	20·58	2·39379	·47864	·69184
·39	8·19	·86850	·36789	·60654	·989	20·769	2·40053	·46687	·68328
·40	8·40	·89844	·37490	·61229	·990	20·790	2·40121	·46646	·68297
·41	8·61	·92851	·38176	·61786	·991	20·811	2·40734	·46499	·68190
·42	8·82	·95869	·38840	·62329	·992	20·832	2·40236	·46339	·68072
·43	9·03	·98896	·39509	·62863	·993	20·853	2·40284	·46197	·67968
·44	9·24	1·01933	·40156	·63369	·994	20·874	2·40338	·45985	·67812
·45	9·45	1·04735	·40790	·63867	·995	20·895	2·40383	·45785	·67665
·46	9·66	1·08027	·41401	·64344	·996	20·916	2·40424	·45567	·67503
·47	9·87	1·11082	·42018	·64821	·997	20·937	2·40461	·45318	·67319
·48	10·08	1·14403	·42607	·65275	·998	20·958	2·40491	·45025	·67101
·49	10·29	1·17201	·43185	·65715	·999	20·979	2·40515	·43794	·66024
·50	10·50	1·19987	·43750	·66143	1·000	21·000	2·40527	·43750	·66143

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·024	·000168	·001327	·03642	·51	12·24	1·610792	·50629	·71155
·002	·048	·000476	·002660	·05157	·52	12·48	1·650776	·41240	·71582
·003	·072	·000876	·003174	·05634	·53	12·72	1·690724	·51833	·71995
·004	·096	·001268	·005224	·07297	·54	12·96	1·730624	·52424	·72404
·005	·120	·001884	·006558	·08159	·55	13·20	1·770460	·52977	·72785
·006	·144	·002476	·007983	·08934	·56	13·44	1·8[illegible]0220	·53522	·73159
·007	·168	·003016	·009201	·09592	·57	13·68	1·848880	·54050	·73519
·008	·192	·003808	·010629	·10310	·58	13·92	1·889424	·54559	·73864
·009	·216	·004540	·011946	·10930	·59	14·16	1·928844	·55053	·74198
·010	·240	·005316	·013267	·11518	·60	14·14	1·968112	·55532	·74520
·011	·264	·006132	·014590	·12079	·61	14·64	2·047220	·55985	·74823
·02	·48	·014996	·026420	·16254	·62	14·88	2·046148	·56425	·75116
·03	·72	·027464	·039441	·19860	·63	15·12	2·084876	·56846	·75395
·04	·96	·042152	·052215	·22850	·64	15·36	2·123388	·57247	·75661
·05	1·20	·058724	·065036	·25502	·65	15·60	2·161672	·57629	·75914
·06	1·44	·076956	·077743	·27883	·66	15·84	2·199700	·57993	·76153
·07	1·68	·096672	·090258	·30043	·67	16·08	2·237456	·58337	·76378
·08	1·92	·117740	·10265	·32039	·68	16·32	2·274928	·58659	·76589
·09	2·16	·140048	·11491	·33898	·69	16·56	2·312088	·58364	·76788
·10	2·40	·163500	·12704	·35642	·70	16·80	2·348920	·59247	·76972
·11	2·64	·188024	·13904	·37288	·71	17·04	2·385400	·59509	·77142
·12	2·88	·213540	·15092	·38669	·72	17·28	2·421512	·59849	·77297
·13	3·12	·239996	·16266	·40331	·73	17·52	2·457232	·59967	·77439
·14	3·36	·267332	·17427	·41746	·74	17·76	2·492540	·60164	·77565
·15	3·60	·295500	·18575	·43100	·75	18·00	2·527408	·60337	·77677
·16	3·84	·324448	·16710	·44396	·76	18·24	2·561812	·60487	·77774
·17	4·08	·354144	·20832	·45642	·77	18·48	2·595732	·60613	·77854
·18	4·32	·384540	·21941	·46841	·78	18·72	2·629136	·60713	·77919
·19	4·56	·415600	·23036	·47996	·79	18·96	2·662000	·60789	·77967
·20	4·80	·447296	·24118	·49110	·80	19·20	2·694296	·60838	·77999
·21	5·04	·479592	·25187	·50186	·81	12·44	2·725992	·60864	·78013
·22	5·28	·512456	·26242	·51227	·82	19·68	2·757052	·60854	·78009
·23	5·52	·545860	·27283	·52223	·83	19·92	2·787448	·60818	·77986
·24	5·76	·577780	·28311	·53208	·84	20·16	2·817144	·60752	·77944
·25	6·00	·614284	·29325	·54152	·85	20·20	2·846092	·60653	·77880
·26	6·24	·649052	·30325	·55069	·86	20·64	2·874260	·60521	·77795
·27	6·48	·684360	·31212	·55957	·87	20·88	2·901596	·60352	·77687
·28	6·72	·720080	·32284	·56819	·88	21·12	2·928052	·60146	·77554
·29	6·96	·756192	·33243	·57657	·89	21·36	2·953568	·59899	·77394
·30	7·20	·792672	·34188	·58470	·90	21·60	2·978092	·50607	·77205
·31	7·44	·829504	·35119	·59261	·91	21·84	3·001544	·59267	·76985
·32	7·68	·866664	·36035	·60029	·92	22·10	3·023852	·58874	·76729
·33	7·72	·906536	·36937	·60776	·93	22·32	3·044920	·58420	·76433
·34	8·16	·941892	·37825	·61502	·94	22·56	3·064636	·57896	·76089
·35	8·40	·979920	·38699	·62208	·95	22·80	3·082868	·57300	·75696
·36	8·64	1·018204	·39557	·62894	·96	23·04	3·099440	·56582	·75221
·37	8·88	1·056716	·40401	·63562	·97	23·28	3·114128	·55740	·74659
·38	9·12	1·095444	·41231	·64211	·98	23·52	3·126596	·54703	·73961
·39	9·36	1·034372	·42045	·64842	·989	23·73	3·135460	·53479	·73130
·40	9·60	1·173480	·42846	·65457	·990	23·76	3·136276	·53309	·73013
·41	9·84	1·212748	·43630	·66053	·991	23·78	3·137052	·53147	·72898
·42	10·08	1·252168	·44400	·66633	·992	23·80	3·137784	·53959	·72772
·43	10·32	1·291712	·45154	·67197	·993	23·83	3·138476	·52808	·72669
·44	10·56	1·331372	·45893	·67744	·994	23·85	3·139116	·52555	·72494
·45	10·30	1·371132	·46617	·68276	·995	23·88	3·139708	·52327	·72337
·46	11·04	1·410968	·47316	·68787	·996	23·90	3·140244	·52077	·72164
·47	11·28	1·450868	·48021	·69297	·997	23·92	3·140716	·51793	·71967
·48	11·52	1·490816	·48694	·69781	·998	23·95	3·141116	·51458	·71734
·49	11·76	1·530800	·49355	·70253	·999	23·97	3·141424	·50050	·70746
·50	12·00	1·570796	·50000	·70711	1·000	24·00	3·141592	·50000	·70711

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·027	·000213	·001493	·03863	·51	13·77	2·03865	·56958	·75470
·002	·054	·000603	·002993	·05470	·52	14·04	2·08926	·57645	·75924
·003	·081	·001114	·003572	·05975	·53	14·31	2·13490	·58311	·76361
·004	·108	·001706	·005991	·07739	·54	14·58	2·19032	·58977	·76796
·005	·135	·002385	·007491	·08657	·55	14·85	2·24071	·59460	·77110
·006	·162	·003128	·008982	·09476	·56	15·12	2·29105	·60226	·77605
·007	·189	·003944	·010351	·10174	·57	15·39	2·34125	·60806	·77974
·008	·216	·004819	·011958	·10960	·58	15·66	2·39130	·61380	·78345
·009	·243	·005746	·013439	·11592	·59	15·93	2·43950	·61957	·78713
·010	·270	·006728	·014926	·12245	·60	16·20	2·49089	·62500	·79039
·011	·297	·007761	·016413	·12664	·61	16·47	2·54038	·62984	·79362
·02	·54	·018979	·029723	·17240	·62	16·74	2·58965	·63500	·79687
·03	·81	·034759	·044370	·21064	·63	17·01	2·62050	·63950	·79969
·04	1·08	·053348	·058741	·24236	·64	17·28	2·68741	·64402	·80251
·05	1·35	·074151	·073166	·27049	·65	17·55	2·73586	·64834	·80519
·06	1·62	·097173	·087461	·29573	·66	17·82	2·78399	·65241	·80772
·07	1·89	·12235	·10154	·31865	·67	18·09	2·83178	·65628	·81011
·08	2·16	·14901	·11547	·33982	·68	18·36	2·87920	·65991	·81235
·09	2·43	·17724	·12927	·35954	·69	18·63	2·92623	·66335	·81446
·10	2·70	·20692	·14291	·37804	·70	18·90	2·97285	·66652	·81641
·11	2·97	·23796	·15642	·39550	·71	19·17	3·01902	·66947	·81821
·12	3·24	·27088	·16977	·41204	·72	19·44	3·05768	·67217	·81986
·13	3·51	·30374	·18299	·42777	·73	19·71	3·10993	·67463	·82136
·14	3·78	·34622	·19601	·44278	·74	19·98	3·15462	·67684	·82270
·15	4·05	·37399	·20897	·45713	·75	20·25	3·19875	·67880	·82389
·16	4·32	·41062	·22174	·47089	·76	20·52	3·24229	·68048	·82491
·17	4·59	·44821	·23436	·48411	·77	20·79	3·28522	·68189	·82577
·18	4·86	·48668	·24683	·49682	·78	21·06	3·32749	·68304	·82646
·19	5·13	·52599	·25915	·50907	·79	21·33	3·36656	·68388	·82697
·20	5·40	·56597	·27070	·52029	·80	21·60	3·40996	·68443	·82730
·21	5·67	·60698	·28334	·53230	·81	21·87	3·45008	·68461	·82745
·22	5·94	·64857	·29522	·54334	·82	22·14	3·48939	·68460	·82741
·23	6·21	·68924	·30693	·55401	·83	22·41	3·52786	·68420	·82716
·24	6·48	·73376	·31849	·56435	·84	22·68	3·56544	·68346	·82671
·25	6·75	·77737	·32990	·57437	·85	22·95	3·60210	·68235	·82604
·26	7·02	·82145	·34116	·58408	·86	23·22	3·63773	·68086	·82514
·27	7·29	·86415	·35307	·59351	·87	23·49	3·67239	·67896	·82399
·28	7·56	·91135	·36320	·60266	·88	23·76	3·70581	·67664	·82258
·29	7·83	·95705	·37398	·61013	·89	24·03	3·73810	·67386	·82089
·30	8·10	1·00322	·38461	·62017	·90	24·30	3·76914	·67058	·82889
·31	8·37	1·04984	·39599	·62927	·91	24·57	3·79882	·66675	·81655
·32	8·64	1·09687	·40539	·63670	·92	24·84	3·82706	·66233	·81383
·33	8·91	1·14429	·41554	·64462	·93	25·11	3·85372	·65731	·81069
·34	9·18	1·19208	·42552	·65232	·94	25·38	3·87867	·65133	·80705
·35	9·45	1·23735	·43539	·65981	·95	25·65	3·90175	·64463	·80288
·36	9·72	1·28866	·44502	·66709	·96	25·92	3·83343	·63640	·79774
·37	9·99	1·33740	·45451	·67417	·97	26·19	3·94131	·62707	·79188
·38	10·26	1·38964	·46384	·68106	·98	26·46	3·95709	·61540	·78447
·39	10·53	1·43568	·47301	·68775	·989	26·703	3·96831	·60026	·77476
·40	10·80	1·48518	·48201	·69427	·990	26·730	3·96934	·59973	·77442
·41	11·07	1·53488	·49083	·70059	·991	26·757	3·97031	·59785	·77321
·42	11·34	1·58842	·49949	·70675	·992	26·784	3·97125	·59578	·77187
·43	11·61	1·63482	·50798	·71273	·993	26·811	3·97213	·59396	·77069
·44	11·88	1·68501	·51630	·71854	·994	26·838	3·97294	·59124	·76892
·45	12·15	1·73134	·52444	·72418	·995	26·865	3·97369	·58867	·76725
·46	12·42	1·78575	·53230	·72959	·996	26·892	3·97436	·58586	·76541
·47	12·69	1·84473	·54273	·73670	·997	26·919	3·97495	·58266	·76332
·48	12·96	1·88681	·54781	·74014	·998	26·946	3·97547	·57890	·76085
·49	13·23	1·93741	·55524	·74514	·999	26·973	3·97586	·56306	·75037
·50	13·50	1·98803	·56250	·74999	1·000	27·000	3·97607	·56250	·74999

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	$\sqrt{R}$ in Feet.
·001	·030	·000263	·001658	·04073	·51	15·30	2·52324	·63286	·79553
·002	·060	·000744	·002647	·05133	·52	15·60	2·57933	·64050	·80031
·003	·090	·001368	·003968	·06299	·53	15·90	2·63568	·64790	·80492
·004	·120	·002106	·006656	·08158	·54	16·20	2·70410	·65530	·80950
·005	·150	·003706	·008323	·09123	·55	16·50	2·76631	·66067	·81282
·006	·180	·003863	·009979	·09984	·56	16·80	2·82846	·66902	·81794
·007	·210	·004869	·011501	·10749	·57	17·10	2·89043	·67562	·82196
·008	·240	·005949	·013286	·11526	·58	17·40	2·95222	·68200	·82583
·009	·270	·007094	·014932	·12219	·59	17·70	3·01381	·68842	·82971
·010	·300	·008306	·016584	·12878	·60	18·00	3·07517	·69413	·83314
·011	·030	·009582	·018279	·13504	·61	18·30	3·13628	·69982	·83655
·02	·060	·023431	·033025	·18172	·62	18·60	3·19710	·70556	·83997
·03	·090	·042715	·049301	·22203	·63	18·90	3·25761	·71056	·84294
·04	1·20	·065862	·065268	·25547	·64	19·20	3·31779	·71558	·84592
·05	1·50	·091756	·081295	·28186	·65	19·50	3·37761	·72038	·84875
·06	1·80	·11996	·097179	·31173	·66	19·80	3·43703	·72491	·85141
·07	2·10	·15105	·11282	·33589	·67	20·10	3·49602	·72920	·85393
·08	2·40	·18439	·12831	·35820	·68	20·40	3·55457	·73323	·85629
·09	2·70	·21882	·14363	·37899	·69	20·70	3·61263	·73705	·85852
·10	3·00	·25546	·15879	·39849	·70	21·00	3·67018	·74058	·86057
·11	3·30	·29378	·17380	·41689	·71	21·30	3·72718	·74385	·86247
·12	3·60	·33365	·18864	·43433	·72	21·60	3·77491	·74686	·86421
·13	3·90	·37499	·20332	·45091	·73	21·90	3·83942	·74959	·86579
·14	4·20	·41770	·21784	·46673	·74	22·20	3·89459	·75205	·86720
·15	4·50	·46171	·23219	·48186	·75	22·50	3·94907	·75422	·86846
·16	4·80	·50695	·24638	·49636	·76	22·80	4·00283	·75609	·86953
·17	5·10	·55335	·26040	·51029	·77	23·10	4·05584	·75766	·87043
·18	5·40	·60084	·27426	·52370	·78	23·40	4·10802	·75893	·87116
·19	5·70	·64937	·28795	·53661	·79	23·70	4·15625	·75987	·87170
·20	6·00	·69890	·30078	·54843	·80	24·00	4·20983	·76047	·87205
·21	6·30	·74936	·31483	·56109	·81	24·30	4·25936	·76075	·87221
·22	6·60	·80071	·32802	·57273	·82	24·60	4·29799	·76067	·87216
·23	6·90	·85092	·34104	·58401	·83	24·90	4·35538	·76023	·87191
·24	7·20	·90588	·36213	·60177	·84	25·20	4·40178	·75940	·87143
·25	7·50	·95972	·36656	·60544	·85	25·50	4·44704	·75816	·87072
·26	7·80	1·01414	·37906	·61568	·86	25·80	4·49103	·75651	·87977
·27	8·10	1·06682	·39140	·62550	·87	26·10	4·53374	·75440	·86856
·28	8·40	1·12512	·40355	·63526	·88	26·40	4·57508	·75182	·86708
·29	8·70	1·18155	·41553	·64462	·89	26·70	4·61495	·74873	·86529
·30	9·00	1·23855	·42735	·65372	·90	27·00	4·65327	·74509	·86318
·31	9·30	1·29610	·43999	·66332	·91	27·30	4·68991	·74084	86072
·32	9·60	1·35416	·45044	·67114	·92	27·60	4·72476	·73592	·85785
·33	9·90	1·41890	·46171	·67949	·93	27·90	4·75768	·73025	·85454
·34	10·20	1·47170	·47281	·68761	·94	28·20	4·78849	·72370	·85070
·35	10·50	1·52760	·48372	·69550	·95	28·50	4·81698	·71625	·84632
·36	10·80	1·59094	·49446	·70318	·96	28·80	4·84287	·70727	·84099
·37	11·10	1·68957	·50501	·71064	·97	29·10	4·86582	·69675	·83471
·38	11·40	1·71166	·51538	·71790	·98	29·40	4·88530	·68378	·82691
·39	11·70	1·77245	·52556	·72496	·989	29·670	4·89915	·66695	·81667
·40	12·00	1·83359	·53557	·73183	·990	29·700	4·90043	·66637	·81631
·41	12·30	1·89491	·54537	·73849	·991	29·730	4·90162	·66428	·81503
·42	12·60	1·95651	·55499	·74498	·992	29·760	4·90278	·66198	·81362
·43	12·90	2·02295	·56442	·75128	·993	29·790	4·90386	·66011	·81247
·44	13·20	2·08026	·57366	·75740	·994	29·820	4·90486	·65693	·81051
·45	13·50	2·14239	·58271	·76335	·995	29·850	4·90579	·65408	·80875
·46	13·80	2·20463	·59145	·76906	·996	29·880	4·90663	·65095	·80682
·47	14·10	2·26698	·60026	·77477	·997	29·910	4·90736	·64740	·80461
·48	14·40	2·32939	·60868	·78019	.998	29·940	4·90799	·64322	·80201
·49	14·70	2·39187	·61694	·78545	·999	29·970	4·90847	·62563	·79096
·50	15·00	2·45436	·62500	·79056	1·000	30·000	4·90873	·62500	·79056

Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·033	·000317	·001825	·04271	·51	16·83	3·04540	·69615	·83435
·002	·066	·000899	·003657	·06047	·52	17·16	3·12099	·70455	·83937
·003	·099	·001656	·004365	·06606	·53	17·49	3·18917	·71269	·84421
·004	·132	·002548	·007322	·08556	·54	17·82	3·27196	·72066	·84901
·005	·165	·003562	·009155	·09568	·55	18·15	3·34723	·72674	·85249
·006	·198	·004674	·010976	·10477	·56	18·48	3·42244	·73593	·85786
·007	·231	·004679	·012651	·11248	·57	18·81	3·49742	·74319	·86208
·008	·264	·007199	·014615	·12089	·58	19·14	3·57219	·75020	·86614
·009	·297	·008584	·016425	·12816	·59	19·47	3·64672	·75726	·87020
·010	·330	·010051	·018243	·13506	·60	19·80	3·72096	·76354	·87381
·011	·363	·011593	·020060	·14163	·61	20·13	3·79490	·76980	·87738
·02	·66	·028351	·036328	·19059	·62	20·46	3·86849	·77611	·88097
·03	·99	·051924	·054231	·23287	·63	20·79	3·94171	·78161	·88409
·04	1·32	·079693	·071794	·26794	·64	21·12	4·01453	·78714	·88721
·05	1·65	·11102	·089425	·29904	·65	21·45	4·08691	·79242	·88018
·06	1·98	·14509	·10689	·32695	·66	21·78	4·15880	·79740	·89297
·07	2·31	·18277	·12410	·35228	·67	22·11	4·23019	·80212	·89561
·08	2·64	·22260	·14114	·37568	·68	22·44	4·30103	·80656	·89808
·09	2·97	·26477	·15799	·39749	·69	22·77	4·37129	·81076	·90042
·10	3·30	·30911	·17467	·41794	·70	23·10	4·44092	·81464	·90257
·11	3·63	·35548	·19118	·43724	·71	23·43	4·50989	·81824	·90456
·12	3·96	·40372	·20750	·45553	·72	23·76	4·56764	·82155	·90639
·13	4·29	·45374	·22365	·47292	·73	24·09	4·64570	·82455	·90805
·14	4·62	·50542	·23962	·48951	·74	24·42	4·71246	·82725	·90953
·15	4·95	·55867	·25541	·50538	·75	24·75	4·77838	·82964	·91084
·16	5·28	·61340	·27101	·52059	·76	25·08	4·84332	·83169	·91197
·17	5·61	·66955	·28644	·53520	·77	25·41	4·90755	·83342	·91292
·18	5·94	·72702	·30168	·54926	·78	25·74	4·97070	·83482	·91368
·19	6·27	·78574	·31674	·56280	·79	26·07	5·02906	·83586	·91425
·20	6·60	·84566	·33086	·57520	·80	26·40	5·09390	·83652	·91461
·21	6·93	·90672	·34631	·58848	·81	26·73	5·15382	·83683	·91478
·22	7·26	·96886	·36082	·60068	·82	27·06	5·21255	·83674	·91473
·23	7·59	1·02961	·37428	·61249	·83	27·39	5·27001	·83625	·91446
·24	7·92	1·09612	·38927	·62392	·84	27·72	5·32616	·83534	·91397
·25	8·25	1·16126	·40321	·63499	·85	28·05	5·38092	·83398	·91301
·26	8·58	1·22711	·41697	·64573	·86	28·38	5·43414	·83216	·91222
·27	8·91	1·29089	·43054	·65615	·87	28·71	5·48570	·82984	·91096
·28	9·24	1·36140	·44391	·66627	·88	29·04	5·53584	·82701	·90940
·29	9·57	1·42967	·45719	·67616	·89	29·37	5·58409	·82360	·90752
·30	9·90	1·49864	·47008	·68562	·90	29·70	5·63045	·81960	·90506
·31	10·23	1·56829	·48399	·69570	·91	30·03	5·67479	·81492	·90273
·32	10·56	1·63853	·49548	·70390	·92	30·36	5·71697	·80951	·90972
·33	10·89	1·70938	·50788	·71266	·93	30·69	5·75680	·80327	·89625
·34	11·22	1·78076	·52009	·72117	·94	31·02	5·79407	·79607	·89223
·35	11·55	1·84840	·53210	·72945	·95	31·35	5·82854	·78788	·88762
·36	11·88	1·92504	·54391	·73750	·96	31·68	5·85987	·77800	·88204
·37	12·21	1·99785	·55551	·74533	·97	32·01	5·88763	·76642	·87545
·38	12·54	2·07111	·56692	·75641	·98	32·34	5·91122	·75216	·86727
·39	12·87	2·14467	·57812	·76034	·989	32·571	5·92798	·73365	·85653
·40	13·20	2·21861	·58913	·76755	·990	32·670	5·92952	·73300	·85615
·41	13·53	2·29285	·59991	·77455	·991	32·703	5·93096	·73071	·85481
·42	13·86	2·36737	·61049	·78134	·992	32·736	5·93237	·72818	·85333
·43	14·19	2·44777	·62087	·78795	·993	32·769	5·93367	·72596	·85203
·44	14·52	2·51712	·63103	·79437	·994	32·802	5·93489	·72262	·85007
·45	14·85	2·58633	·64098	·80061	·995	32·835	5·93601	·71949	·84822
·46	15·18	2·66761	·65059	·80659	·996	32·868	5·93702	·71605	·84620
·47	15·51	2·74304	·66029	·81258	·997	32·901	5·93791	·71215	·84388
·48	15·84	2·81857	·66954	·81825	·998	32·934	5·93867	·70754	·84115
·49	16·17	2·89416	·67863	·82379	·999	32·967	5·93925	·68819	·82957
·50	16·50	2·96978	·68750	·82915	1·000	33·000	5·93956	·68750	·82915

Depth on Invert ÷ by Diameter	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.	Depth on Invert ÷ by Diameter.	Depth on Invert in Ins.	Area of Cross Section in Square Feet.	Hydraulic Mean Depth. R in Feet.	√R in Feet.
·001	·036	·000378	·001990	·04461	·51	18·36	3·624232	·75944	·87146
·002	·072	·001071	·003990	·06316	·52	18·72	3·714246	·76861	·87670
·003	·108	·001971	·004761	·06900	·53	19·08	3·804129	·77749	·88175
·004	·144	·003033	·007987	·08937	·54	19·44	3·893904	·78636	·88677
·005	·180	·004339	·009987	·09993	·55	19·80	3·983535	·79466	·89143
·006	·216	·005571	·011811	·10940	·56	20·16	4·072995	·80283	·89601
·007	·252	·007011	·013802	·11748	·57	20·52	4·162230	·81075	·90042
·008	·288	·008568	·016018	·12627	·58	20·88	4·251204	·81841	·90466
·009	·324	·010115	·017919	·13386	·59	21·24	4·339899	·82580	·90874
·010	·360	·011961	·019902	·14107	·60	21·60	4·428252	·83298	·91267
·011	·396	·013797	·021884	·14793	·61	21·96	4·516245	·83979	·91640
·02	·72	·033741	·039631	·19907	·62	22·32	4·603833	·84637	·91998
·03	1·08	·061794	·059161	·24323	·63	22·68	4·690971	·85267	·92340
·04	1·44	·094842	·078322	·27986	·64	23·04	4·777623	·85870	·92666
·05	1·80	·132129	·097555	·31234	·65	23·40	4·863762	·86444	·92975
·06	2·16	·173151	·11661	·34149	·66	23·76	4·949325	·86989	·93268
·07	2·52	·217512	·13539	·36795	·67	24·12	5·034276	·87503	·93544
·08	2·88	·264915	·15397	·39239	·68	24·48	5·118588	·87988	·93802
·09	3·24	·315108	·17236	·41517	·69	24·84	5·202198	·88445	·94045
·10	3·60	·367875	·19056	·43653	·70	25·20	5·285070	·88870	·94271
·11	3·96	·423054	·20856	·45674	·71	25·56	5·367150	·89263	·94479
·12	4·32	·480465	·22637	·47578	·72	25·92	5·448402	·89624	·94670
·13	4·68	·539991	·24399	·49395	·73	26·28	5·518772	·89952	·94843
·14	5·04	·601497	·26141	·51128	·74	26·64	5 608115	·90246	·94998
·15	5·40	·664875	·27863	·52786	·75	27·00	5·686668	·90506	·95134
·16	5·76	·730008	·29565	·54373	·76	27·36	5·764077	·90731	·95252
·17	6·12	·796824	·31249	·55900	·77	27·72	5·840397	·90919	·95351
·18	6·48	·865115	·32912	·57369	·78	28·08	5·915556	·91070	·95431
·19	6·84	·935100	·34555	·58783	·79	28·44	5·989500	·91184	·95490
·20	7·20	1·006416	·36177	·60147	·80	28·80	6·062166	·91257	·95528
·21	7·56	1·079082	·37780	·61466	·81	29·16	6·133482	·91292	·95546
·22	7·96	1·153026	·39453	·62740	·82	29·52	6·203367	·91281	·95541
·23	8·28	1·228185	·40925	·63973	·83	29·88	6·271758	·91227	·95513
·24	8·64	1·304505	·42466	·65166	·84	30·24	6·338574	·91128	·95461
·25	9·00	1·381914	·43988	·66323	·85	30·60	6·403707	·90980	·95383
·26	9·36	1·460367	·45488	·67445	·86	30·96	6·467085	·90781	·95279
·27	9·72	1·539810	·46968	·68533	·87	31·32	6·528591	·90529	·95146
·28	10·08	1·620180	·48427	·69590	·88	31·68	6·588117	·90219	·94984
·29	10·44	1·701432	·49865	·70615	·89	32·04	6·645528	·89848	·94788
·30	10·80	1·783512	·51284	·71613	·90	32·40	6·700707	·89411	·94557
·31	11·16	1·866384	·52678	·72580	·91	32·76	6·753074	·88901	·94287
·32	11·52	1·949994	·54052	·73520	·92	33·12	6·793667	·88311	·93973
·33	11·88	2·034306	·55406	·74435	·93	33·48	6·851070	·87630	·93610
·34	12·24	2·119257	·56737	·75324	·94	33·84	6·895431	·86844	·93190
·35	12·60	2·204820	·58047	·76189	·95	34·20	6·936453	·85949	·92709
·36	12·96	2·290959	·59336	·77030	·96	34·56	6·973740	·85069	·92233
·37	13·32	2·377611	·60602	·77847	·97	34·92	7·006788	·83610	·91439
·38	13·68	2·460749	·61846	·78642	·98	35·28	7·034841	·82054	·90584
·39	14·04	2·552337	·63068	·79415	·989	35·60	7·054785	·80220	·89565
·40	14·40	2·640330	·64249	·80168	·990	35·64	7·056621	·79764	·89423
·41	14·76	2·728683	·65445	·80898	·991	35·67	7·058367	·79713	·89282
·42	15·12	2·817378	·66600	·81608	·992	35·71	7·060014	·79448	·89128
·43	15·48	2·906352	·67731	·82280	·993	35·74	7·061571	·79194	·88990
·44	15·84	2·995587	·68840	·82970	·994	35·78	7·063011	·78832	·88787
·45	16·20	3·085047	·69924	·83621	·995	35·82	7·064353	·78488	·88593
·46	16·56	3·174678	·70974	·84246	·996	35·85	7·065549	·78115	·88382
·47	16·92	3·264723	·72032	·84872	·997	35·89	7·066711	·77689	·88141
·48	17·28	3·354336	·73042	·85464	·998	35·92	7·706511	·77187	·87856
·49	17·64	3·444300	·74033	·86042	·999	35·96	7·068204	·75075	·86645
·50	18·00	3·534291	·75000	·86602	1·000	36·00	7·068582	·75000	·86602

TABLE 43.—GIVING THE VALUES OF A, R, AND THE $\sqrt{R}$ FOR CIRCULAR PIPES, CONDUITS AND SEWERS, FLOWING FULL; WHEN HALF FULL REDUCE A BY ONE HALF.

Diameter. Feet.	Inches.	A = Area in Square Feet.	R in Feet.	$\sqrt{R}$ in Feet.	Diameter. Feet.	Inches.	A = Area in Square Feet.	R in Feet.	$\sqrt{R}$ in Feet.
	⅜	·00077	·0078	·088	4	7	16·499	1·146	1·070
	½	·00136	·0104	·102	4	8	17·104	1·167	1·080
	¾	·00307	·0156	·125	4	9	17·721	1·187	1·089
	1	·00545	·0208	·144	4	10	18·348	1·208	1·099
	1¼	·00852	·0260	·161	4	11	18·986	1·229	1·109
	1½	·01227	·0312	·177	5	0	19·635	1·25	1·118
	1¾	·01670	·0364	·191	5	1	20·295	1·271	1·127
	2	·02182	·0417	·204	5	2	20·966	1·292	1·137
	2½	·0341	·052	·228	5	3	21·648	1·312	1·146
	3	·0491	·063	·251	5	4	22·340	1·333	1·155
	4	·0873	·084	·290	5	5	23·044	1·354	1·164
	5	·136	·104	·323	5	6	23·758	1·375	1·173
	6	·196	·125	·354	5	7	24·484	1·396	1·181
	7	·267	·146	·382	5	8	25·220	1·417	1·190
	8	·349	·167	·408	5	9	25·967	1·437	1·199
	9	·442	·187	·433	5	10	26·725	1·558	1·208
	10	·545	·208	·456	5	11	27·494	1·479	1·216
	11	·660	·229	·479	6	0	28·274	1·5	1·225
1	0	·785	·250	·5	6	3	30·680	1·562	1·250
1	1	·922	·271	·52	6	6	33·183	1·625	1·275
1	2	1·069	·292	·54	6	9	35·785	1·687	1·299
1	3	1·227	·313	·559	7	0	38·485	1·75	1·323
1	4	1·396	·333	·577	7	3	41·283	1·812	1·346
1	5	1·576	·354	·595	7	6	44·179	1·879	1·369
1	6	1·767	·375	·612	7	9	47·173	1·937	1·392
1	7	1·969	·396	·629	8	0	50·266	2·	1·414
1	8	2·182	·417	·646	8	3	53·456	2·062	1·436
1	9	2·405	·437	·661	8	6	56·745	2·125	1·458
1	10	2·640	·458	·677	8	9	60·132	2·187	1·479
1	11	2·885	·479	·692	9	0	63·617	2·25	1·500
2	0	3·142	·5	·707	9	3	67·201	2·312	1·521
2	1	3·409	·521	·722	9	6	70·882	2·375	1·541
2	2	3·687	·542	·736	9	9	74·662	2·437	1·561
2	3	3·976	·562	·75	10	0	78·540	2·5	1·581
2	4	4·276	·583	·764	10	3	82·516	2·562	1·601
2	5	4·587	·604	·777	10	6	86·590	2·625	1·620
2	6	4·909	·625	·79	10	9	90·763	2·687	1·639
2	7	5·241	·646	·804	11	0	95·033	2·750	1·658
2	8	5·585	·667	·817	11	3	99·402	2·812	1·677
2	9	5·939	·687	·829	11	6	103·869	2·875	1·696
2	10	6·305	·708	·842	11	9	108·434	2·937	1·714
2	11	6·681	·729	·854	12	0	113·098	3·	1·732
3	0	7·068	·75	·866	12	3	117·859	3·062	1·750
3	1	7·466	·771	·878	12	6	122·719	3·125	1·768
3	2	7·875	·792	·89	12	9	127·677	3·187	1·785
3	3	8·295	·812	·901	13	0	132·733	3·25	1·803
3	4	8·726	·833	·913	13	3	137·887	3·312	1·820
3	5	9·169	·854	·924	13	6	143·139	3·375	1·837
3	6	9·621	·875	·935	13	9	148·490	3·437	1·854
3	7	10·084	·896	·946	14	0	153·938	3·5	1·871
3	8	10·559	·917	·957	14	6	165·130	3·625	1·904
3	9	11·044	·937	·968	15	0	176·715	3·75	1·936
3	10	11·541	·958	·979	15	6	188·692	3·875	1·968
3	11	12·048	·979	·99	16	0	201·062	4·	2·
4	0	12·566	1·	1·	16	6	213·825	4·125	2·031
4	1	13·096	1·021	1·01	17	0	226·981	4·250	2·061
4	2	13·635	1·042	1·021	17	6	240·529	4·375	2·091
4	3	14·186	1·062	1·031	18	0	254·470	4·5	2·121
4	4	14·748	1·083	1·041	19	0	283·529	4·75	2·180
4	5	15·321	1·104	1·051	20	0	314·159	5·	2·236
4	6	15·904	1·125	1·061					

TABLE 44.—AREA AND HYDRAULIC MEAN DEPTH OF OVAL SEWERS. (OLD FORM.)

Dimensions of Sewer.				Flowing full.			Flowing two-thirds full.			Flowing one-third full.		
Width.		Height.		Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.	Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.	Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.
Ft.	Ins.	Ft.	Ins.									
1	0	1	6	1·1485	·2897	·53823	·7558	·3157	·56187	·2840	·2066	·45453
1	2	1	9	1·5632	·3380	·58137	1·0287	·3683	·60687	·3865	·2410	·49091
1	4	2	0	2·0418	·3863	·62007	1·3436	·4209	·64876	·5049	·2755	·52488
1	6	2	3	2·5841	·4345	·65915	1·7005	·4735	·68811	·6390	·3099	·55668
1	8	2	6	3·1903	·4828	·69483	2·0994	·5262	·72539	·7889	·3443	·58677
1	10	2	9	3·8602	·5311	·72876	2·5402	·5788	·76078	·9545	·3786	·61530
2	0	3	0	4·5940	·5794	·76118	3·0232	·6314	·79460	1·1360	·4132	·64280
2	2	3	3	5·3916	·6277	·79227	3·5480	·6840	·82704	1·3332	·4476	·66902
2	4	3	6	6·2529	·6760	·82219	4·1149	·7366	·85825	1·5462	·4820	·69426
2	6	3	9	7·1781	·7242	·85099	4·7237	·7892	·88836	1·7750	·5165	·71867
2	8	4	0	8·1671	·7725	·87891	5·3746	·8418	·91749	2·0195	·5409	·73545
2	10	4	3	9·2199	·8208	·90598	6·0674	·8944	·94572	2·2799	·5852	·76498
3	0	4	6	10·3365	·8691	·93225	6·8022	·9471	·97319	2·5560	·6198	·78727
3	2	4	9	11·5169	·9174	·95780	7·5790	·9997	·99984	2·8479	·6542	·80882
3	4	5	0	12·7611	·9657	·98270	8·3978	1·0523	1·0258	3·1556	·6887	·82987
3	6	5	3	14·0691	1·0139	1·0069	9·2585	1·1049	1·0509	3·4790	·7231	·85015
3	8	5	6	15·4099	1·0622	1·0294	10·1613	1·1576	1·0759	3·8182	·7575	·87034
3	10	5	9	16·8766	1·1105	1·0538	11·1061	1·2102	1·1056	4·1732	·7920	·88994
4	0	6	0	18·3760	1·1588	1·0752	12·0928	1·2628	1·1247	4·5440	·8264	·90906
4	2	6	3	19·9392	1·2071	1·0986	13·1215	1·3154	1·1455	4·9306	·8608	·92779
4	4	6	6	21·5663	1·2554	1·1204	14·1922	1·3680	1·1696	5·3229	·8952	·94615
4	6	6	9	23·2571	1·3036	1·1404	15·3049	1·4206	1·1918	5·7501	·9297	·96420
4	8	7	0	25·0117	1·3519	1·1627	16·4596	1·4733	1·2137	6·1849	·9641	·98186
4	10	7	3	26·8302	1·4002	1·1833	17·6563	1·5258	1·2352	6·6346	·9986	·99929
5	0	7	6	28·7125	1·4485	1·2023	18·8950	1·5785	1·2563	7·1000	1·0330	1·0163
5	2	7	9	30·6649	1·4968	1·2220	20·1757	1·6311	1·2625	7·5812	1·0675	1·0331
5	4	8	0	32·6684	1·5451	1.2430	21·4983	1·6836	1·2975	8·0782	1·1019	1·0485
5	6	8	3	34·7421	1·5933	1·2622	22·8629	1·7363	1·3176	8·5910	1·1363	1·0660
5	8	8	6	36·8796	1·6416	1·2812	24·2696	1·7890	1·3375	9·1196	1·1707	1·0819
5	10	8	9	39·0809	1·6899	1·2999	25·7182	1·8415	1·3570	9·6639	1·2052	1·0965
6	0	9	0	41·3460	1·7382	1·3184	27·2088	1·8942	1·3755	10·2240	1·2396	1·1133
6	2	9	3	43·676	1·787	1·3367	28·742	1·947	1·3953	10·800	1·274	1·1287
6	4	9	6	46·068	1·835	1·3546	30·317	1·999	1·4138	11·391	1·309	1·1441
6	6	9	9	48·525	1·883	1·3722	31·933	2·052	1·4324	11·999	1·343	1·1588
6	8	10	0	51·046	1·931	1·3896	33·592	2·095	1·4474	12·622	1·377	1·1734
6	10	10	3	53·629	1·980	1·4071	35·292	2·157	1·4686	13·261	1·412	1·1882
7	0	10	6	56·278	2·028	1·4240	37·035	2·210	1·4866	13·916	1·446	1·2024
7	4	11	0	61·764	2·124	1·4573	40·646	2·315	1·5215	15·273	1·515	1·2309
7	8	11	6	67·508	2·221	1·4903	44·426	2·420	1·5592	16·693	1·584	1·2585
8	0	12	0	73·506	2·318	1·5224	48·372	2·526	1·5893	18·176	1·653	1·2856
8	4	12	6	79·758	2·414	1·5537	52·487	2·631	1·6220	19·722	1·722	1·3137
8	8	13	0	86·268	2·511	1·5846	56·771	2·736	1·6540	21·331	1·791	1·3382
9	0	13	6	93·031	2·607	1·6146	61·222	2·841	1·6855	23·004	1·859	1·3634
9	4	14	0	100·049	2·704	1·6443	65·840	2·947	1·7166	24·739	1·928	1·3885
9	8	14	6	107·324	2·800	1·6733	70·628	3·052	1·7469	26·538	1·997	1·4131
10	0	15	0	114·853	2·897	1·7020	75·582	3·157	1·7767	28·400	2·066	1·4373
10	6	15	9	126·625	3·042	1·7441	83·330	3·315	1·8207	31·311	2·169	1·4778
11	0	16	6	138·972	3·187	1·7852	91·455	3·473	1·8635	34·364	2·273	1·5076
12	0	18	0	165·388	3·476	1·8644	108·838	3·788	1·9462	40·892	2·479	1·5744

TABLE 45.—AREA AND HYDRAULIC MEAN DEPTH OF OVAL SEWERS. (NEW FORM.)

Dimensions of Sewer.				Flowing full.			Flowing two-thirds full.			Flowing one-third full.		
Width.		Height.		Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.	Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.	Sectional Area. Square Feet.	Hydraulic Mean Depth. Feet.	$\sqrt{R}$ Feet.
Ft.	Ins.	Ft.	Ins									
1	0	1	6	1·1150	·2844	·53329	·7223	·3074	·55443	2·543	·1920	·43817
1	2	1	9	1·5176	·3318	·57602	·9831	·3586	·59883	·3461	·2240	·47328
1	4	2	0	1·9822	·3792	·61549	1·2841	·4099	·64023	·4521	·2560	·50596
1	6	2	3	2·5087	·4266	·65007	1·6252	·4611	·67904	·5722	·2880	·53665
1	8	2	6	3·0972	·4740	·68847	2·0064	·5123	·71575	·7064	·3200	·56568
1	10	2	9	3·7476	·5214	·72208	2·4277	·5636	·75073	·8547	·3520	·59329
2	0	3	0	4·4600	·5698	·75403	2·8892	·6148	·78409	1·0172	·3840	·61967
2	2	3	3	5·2343	·6162	·78498	3·3908	·6660	·81608	1·1938	·4160	·64498
2	4	3	6	6·0705	·6636	·81461	3·9325	·7173	·84693	1·3845	·4480	·66932
2	6	3	9	6·9687	·7110	·84320	4·5144	·7685	·87664	1·5894	·4800	·69282
2	8	4	0	7·9288	·7584	·87086	5·1364	·8197	·90537	1·8084	·5120	·71554
2	10	4	3	8·9509	·8058	·89766	5·7985	·8710	·93337	2·0415	·5440	·73756
3	0	4	6	10·0349	·8532	·92262	6·5007	·9222	·96031	2·2887	·5760	·75894
3	2	4	9	11·1809	·9006	·94899	7·2431	·9734	·98661	2·5501	·6080	·77902
3	4	5	0	12·3888	·9480	·97365	8·0256	1·0247	1·0122	2·8256	·6400	·80000
3	6	5	3	13·6586	·9954	·99769	8·8482	1·0759	1·5382	3·1152	·6720	·81975
3	8	5	6	14·9904	1·0428	1·0216	9·7110	1·1271	1·0616	3·4190	·7040	·83904
3	10	5	9	16·3842	1·0902	1·0441	10·6139	1·1784	1·0855	3·7369	·7360	·85790
4	0	6	0	17·8399	1·1376	1·0665	11·5569	1·2296	1·1307	4·0689	·7680	·87635
4	2	6	3	19·3575	1·1850	1·0877	12·5400	1·2808	1·1327	4·4150	·8000	·89648
4	4	6	6	20·9371	1·2324	1·1101	13·5633	1·3321	1·1541	4·7753	·8320	·91214
4	6	6	9	22·5786	1·2798	1·1312	14·6267	1·3833	1·1761	5·1479	·8640	·92951
4	8	7	0	24·2820	1·3272	1·1520	15·7302	1·4345	1·1977	5·5382	·8960	·94657
4	10	7	3	26·0474	1·3746	1·1734	16·8738	1·4858	1·2188	5·9408	·9280	·96332
5	0	7	6	27·8748	1·4220	1·1924	18·0576	1·5370	1·2397	6·3576	·9600	·97979
5	2	7	9	29·7641	1·4694	1·2115	19·2815	1·5882	1·2602	6·7885	·9920	·99599
5	4	8	0	31·7153	1·5168	1·2315	20·5455	1·6395	1·2804	7·2335	1·0240	1·0129
5	6	8	3	33·7285	1·5642	1·2506	21·8497	1·6907	1·3002	7·6927	1·0560	1·0286
5	8	8	6	35·8036	1·6116	1·2694	23·1940	1·7419	1·3198	8·1660	1·0880	1·0430
5	10	8	9	37·9407	1·6590	1·2880	24·5784	1·7932	1·3391	8·6534	1·1200	1·0593
6	0	9	0	40·1397	1·7064	1·3072	26·0029	1·8444	1·3580	9·1549	1·1520	1·0757

TABLE 46.—V-SHAPED FLUME, RIGHT-ANGLED CROSS SECTION.

Depth of Water in Feet.	A = Area in Square Feet.	R = Hydraulic Mean Depth in Feet.	$\sqrt{R}$ Feet.	Depth of Water in Feet.	A = Area in Square Feet.	R = Hydraulic Mean Depth in Feet.	$\sqrt{R}$ Feet.
·40	·16	·141	·3755	1·75	3·06	·618	·7861
·5	·25	·177	·4207	1·8	3·24	·636	·7974
·6	·36	·212	·4604	1·9	3·61	·672	·8197
·7	·49	·247	·4969	2·	4·	·707	·8408
·75	·56	·265	·5147	2·1	4·41	·743	·8619
·8	·64	·283	·5319	2·2	4·84	·778	·8820
·9	·81	·318	·5639	2·25	5·06	·795	·8916
1·	1·	·354	·5949	2·3	5·29	·813	·9016
1·1	1·21	·389	·6236	2·4	5·76	·849	·9214
1·2	1·44	·424	·6511	2·5	6·25	·884	·9402
1·25	1·56	·442	·6648	2·6	6·76	·919	·9586
1·3	1·69	·459	·6853	2·7	7·29	·955	·9772
1·4	1·96	·494	·7028	2·75	7·56	·972	·9859
1·5	2·25	·530	·7286	2·8	7·84	·990	·9949
1·6	2·56	·566	·7524	2·9	8·41	1·025	1·0124
1·7	2·89	·601	·7752	3·	9·	1·061	1·0301

Tables for Use with Messrs. Darcy and Bazin's Formula.

TABLE 47.—VALUES OF (ζ) AND (k).

Diameter of Pipe.		ζ		k	
Feet or Inches.		New Pipes.	Old Pipes.	New Pipes.	Old Pipes.
$\frac{1}{24}$	$\frac{1}{2}$	·015	·030	65	46
$\frac{5}{96}$	$\frac{5}{8}$	·013	·026	70	49
$\frac{1}{16}$	$\frac{3}{4}$	·01166	·02333	74	53
$\frac{7}{96}$	$\frac{7}{8}$	·01071	·02142	78	55
$\frac{1}{12}$	1	·01	·02	80	56
$\frac{3}{32}$	$1\frac{1}{8}$	·00944	·01888	82·7	58·4
$\frac{5}{48}$	$1\frac{1}{4}$	·009	·018	84·5	59·8
$\frac{11}{96}$	$1\frac{3}{8}$	·00863	·01727	86·5	61·0
$\frac{1}{8}$	$1\frac{1}{2}$	·008	·01666	87·8	62
$\frac{13}{96}$	$1\frac{5}{8}$	·00807	·01615	89·4	63·2
$\frac{7}{48}$	$1\frac{3}{4}$	·00785	·01571	90·5	64
$\frac{5}{32}$	$1\frac{7}{8}$	·00766	·01533	91·7	64·8
$\frac{1}{6}$	2	·0075	·015	92·6	65·5
$\frac{3}{16}$	$2\frac{1}{4}$	·00722	·01444	94·5	66·8
$\frac{5}{24}$	$2\frac{1}{2}$	·007	·014	95·9	67·8
$\frac{11}{48}$	$2\frac{3}{4}$	·00631	·01363	97·3	63·8
$\frac{1}{4}$	3	·00666	·01333	98·0	70·0
$\frac{13}{48}$	$3\frac{1}{4}$	·00653	·01307	99·5	70·3
$\frac{7}{24}$	$3\frac{1}{2}$	·00642	·01285	100·3	70·9
$\frac{5}{16}$	$3\frac{3}{4}$	·00633	·01266	101·0	71·4
$\frac{1}{3}$	4	·00625	·0125	101·5	71·7
$\frac{3}{8}$	$4\frac{1}{2}$	·00611	·01222	102·7	72·6
$\frac{5}{12}$	5	·006	·012	103·6	73·2
$\frac{11}{24}$	$5\frac{1}{2}$	·00590	·01181	104·4	73·8
$\frac{1}{2}$	6	·005833	·011666	105·0	74·0
$\frac{13}{24}$	$6\frac{1}{2}$	·00576	·01153	105·8	74·8
$\frac{7}{12}$	7	·00571	·01142	106·2	75·0
$\frac{2}{3}$	8	·00562	·01125	107·0	75·6
$\frac{3}{4}$	9	·00555	·001111	107·7	76·1
$\frac{5}{6}$	10	·0055	·0011	108·2	76·5
$\frac{11}{12}$	11	·00545	·0109	108·6	76·8
1	12	·005416	·01083	109·0221	77·0903
$1\frac{1}{12}$	13	·005385	·01077	109·3422	77·3166
$1\frac{1}{6}$	14	·00535715	·0107143	109·626	77·5173
$1\frac{1}{4}$	15	·0053333	·0106666	109·871	77·6902
$1\frac{1}{3}$	16	·0053125	·010625	110·086	77·8424
$1\frac{5}{12}$	17	·00529422	·0105882	110·277	77·9574
$1\frac{1}{2}$	18	·00527644	·0105553	110·461	78·0990
$1\frac{7}{12}$	19	·00526316	·0105263	110·601	78·2064
$1\frac{2}{3}$	20	·005250	·01050	110·740	78·3053
$1\frac{3}{4}$	21	·0052381	·0104762	110·865	78·3933
$1\frac{5}{6}$	22	·0052272	·0104545	110·980	78·4744
$1\frac{11}{12}$	23	·0052174	·0104348	111·0845	78·5486
2	24	·0052083	·0104166	111·181	78·6170
$2\frac{1}{12}$	25	·0052000	·0104000	111·270	78·6800
$2\frac{1}{6}$	26	·0051923	·0103846	111·353	78·7382
$2\frac{1}{4}$	27	·0051859	·0103704	111·429	78·7922
$2\frac{1}{3}$	28	·0051787	·0103571	111·500	78·8426
$2\frac{5}{12}$	29	·00520731	·0103430	111·577	78·8967
$2\frac{1}{2}$	30	·00516666	·0103333	111·629	78·9333
$2\frac{7}{12}$	31	·0051613	·0103226	111·686	78·9747
$2\frac{2}{3}$	32	·00515625	·0103125	111·741	79·0130
$2\frac{3}{4}$	33	·00515151	·0103030	111·793	79·0493
$2\frac{5}{6}$	34	·00514716	·0102941	111·841	79·0836
$2\frac{11}{12}$	35	·00514285	·0102859	111·887	79·1160
3	36	·00513889	·0102777	111·930	79·1464

TABLE 48.—OPEN SEGMENTAL CHANNELS. VALUES OF (c) FOR VARIOUS HYDRAULIC RADII BETWEEN 0·1 AND 1·0.

Hydraulic Mean Depth. R in Feet.	Class I. Cement or Planed Timber Channels.		Class II. Ashlar or Brickwork Channels.		Class III. Rubble Masonry Channels.	
	C_I	Log. C_I	C_{II}	Log. C_{II}	C_{III}	Log. C_{III}
·10	104·98	2·0211447	72·373	1·8595793	38·542	1·5859381
·11	107·43	2·0311643	74·780	1·8737863	40·205	1·6042875
·12	109·61	2·0398829	76·980	1·8863801	41·769	1·6208599
·13	111·56	2·0475429	79·002	1·8976382	43·245	1·6359441
·14	113·32	2·0543325	80·867	1·9077756	44·643	1·6497628
·15	114·91	2·0603924	82·596	1·9169608	45·972	1·6624946
·16	116·36	2·0658371	84·204	1·9253330	47·237	1·6742823
·17	117·69	2·0707566	85·702	1·9329920	48·442	1·6852426
·18	118·91	2·0752264	87·103	1·9400371	49·598	1·6954725
·19	120·03	2·0793047	88·417	1·9465404	50·705	1·7050528
·20	121·07	2·0830416	89·653	1·9525653	51·766	1·7140522
·21	122·03	2·0864798	90·816	1·9581638	52·787	1·7225287
·22	122·92	2·0896521	91·914	1·9633818	53·769	1·7305329
·23	123·76	2·0925899	92·951	1·9682584	54·715	1·7381079
·24	124·54	2·0953184	93·934	1·9728272	55·627	1·7452917
·25	125·27	2·0978587	94·867	1·9771158	56·509	1·7521179
·26	125·96	2·1002336	95·753	1·9811528	57·360	1·7586146
·27	126·60	2·1024518	96·595	1·9849574	58·184	1·7648087
·28	127·22	2·1045336	97·398	1·9885506	58·982	1·7707234
·29	127·78	2·1064897	98·163	1·9919520	59·755	1·7763785
·30	128·33	2·1083328	98·895	1·9951750	60·505	1·7817931
·31	128·84	2·1100691	99·594	1·9982343	61·232	1·7869837
·32	129·33	2·1117107	100·26	2·0011414	61·939	1·7919648
·33	129·79	2·1132640	100·90	2·0039059	62·625	1·7967505
·34	130·23	2·1147359	101·51	2·0065454	63·289	1·8013537
·35	130·65	2·1161347	102·10	2·0090613	63·941	1·8057849
·36	131·05	2·1174625	102·67	2·0114634	64·573	1·8100540
·37	131·43	2·1187263	103·21	2·0137611	65·189	1·8141765
·38	131·80	2·1199303	103·74	2·0159615	65·787	1·8181459
·39	132·15	2·1210786	104·24	2·0180696	66·371	1·8219842
·40	132·48	2·1221754	104·75	2·0201906	66·941	1·8256966
·41	132·80	2·1232235	105·20	2·0220305	67·497	1·8292852
·42	133·12	2·1242257	105·65	2·0238952	68·039	1·8327598
·43	133·36	2·1251883	106·08	2·0256882	68·568	1·8361258
·44	133·69	2·1261091	106·51	2·0274121	69·085	1·8393878
·45	133·96	2·1269934	106·92	2·0290735	69·590	1·8425510
·46	134·22	2·1278409	107·31	2·0306752	70·084	1·8456213
·47	134·46	2·1286081	107·70	2·0322193	70·567	1·8486019
·48	134·72	2·1294423	108·07	2·0337089	70·038	1·8514965
·49	134·95	2·1301964	108·42	2·0351487	71·500	1·8543107
·50	135·18	2·1309250	108·77	2·0365384	71·952	1·8570468
·51	135·40	2·1316265	109·11	2·0378833	72·394	1·8597078
·52	135·60	2·1322574	109·44	2·0391838	72·827	1·8622981
·53	135·81	2·1329556	109·75	2·0404421	73·252	1·8648202
·54	135·98	2·1334947	110·06	2·0416606	73·667	1·8672769
·55	136·20	2·1341971	110·36	2·0428430	74·074	1·8696710
·56	136·39	2·1347837	110·65	2·0439872	74·473	1·8720046
·57	136·57	2·1353570	110·98	2·0452537	74·865	1·8742799
·58	136·74	2·1359076	111·21	2·0461772	75·249	1·8765010
·59	136·91	2·1364434	111·48	2·0472235	75·625	1·8786678
·60	137·07	2·1369609	111·74	2·0482387	75·994	1·8807821
·61	137·10	2·1370523	112·00	2·0492272	76·356	1·8828477
·62	137·37	2·1379000	112·25	2·0501869	76·712	1·8848659
·63	137·54	2·1384415	112·49	2·0511206	77·061	1·8868379
·64	137·68	2·138815	112·85	2·0525296	77·404	1·8887652
·65	137·82	2·1393280	112·95	2·0529134	77·741	1·8906501
·66	137·96	2·1397603	113·18	2·0537736	78·071	1·8924945

TABLE 48—*continued.*

Hydraulic Mean Depth. R in Feet.	Class I. Cement or Planed Timber Channels.		Class II. Ashlar or Brickwork Channels.		Class III. Rubble Masonry Channels.	
	C_I	Log. C_I	C_{II}	Log. C_{II}	C_{III}	Log. C_{III}
·67	138·09	2·1401821	113·39	2·0546113	78·396	1·8942970
·68	138·21	2·1405414	113·61	2·0554295	78·715	1·8960615
·69	138·35	2·1409902	113·82	2·0562247	79·029	1·8977888
·70	138·47	2·1413782	114·02	2·0570016	79·337	1·8994810
·71	138·59	2·1417555	114·22	2·0577583	79·641	1·9011371
·72	138·71	2·1421219	114·41	2·0584963	79·939	1·9027592
·73	138·82	2·1424795	114·53	2·0592169	80·232	1·9043496
·74	138·95	2·1428799	114·79	2·0599366	80·520	1·9059074
·75	139·04	2·1431694	114·97	2·0606072	80·804	1·9074350
·76	139·15	2·1435018	115·15	2·0612782	81·083	1·9089326
·77	139·25	2·1438250	115·32	2·0619329	81·358	1·9104018
·78	139·36	2·1441410	115·49	2·0625744	81·628	1·9118418
·79	139·45	2·1444227	115·66	2·0631994	81·894	1·9132562
·80	139·55	2·1447521	115·82	2·0638127	82·156	1·9146424
·81	139·65	2·1450422	115·98	2·0644107	82·414	1·9160040
·82	139·74	2·1453301	116·14	2·0649968	82·668	1·9173406
·83	139·83	2·1456171	116·29	2·0655693	82·918	1·9186527
·84	139·92	2·1458853	116·44	2·0661313	83·165	1·9199420
·85	140·00	2·1461539	116·59	2·0666793	83·407	1·9212069
·86	140·09	2·1464165	116·73	2·0672186	83·647	1·9224515
·87	140·17	2·1466622	116·88	2·0677437	83·882	1·9236731
·88	140·25	2·1469243	117·01	2·0682596	84·115	1·9248735
·89	140·33	2·1471739	117·15	2·0687665	84·343	1·9260534
·90	140·41	2·1474087	117·28	2·0692607	84·569	1·9272137
·91	140·48	2·1476437	117·42	2·0697474	84·792	1·9283551
·92	140·56	2·1478713	117·55	2·0702230	85·011	1·9294772
·93	140·63	2·1481007	117·65	2·0706909	85·227	1·9305798
·94	140·70	2·1483227	117·80	2·0711477	85·440	1·9316659
·95	140·77	2·1485377	117·92	2·0715966	85·651	1·9327330
·96	140·84	2·1487432	118·04	2·0720378	85·859	1·9337882
·97	140·91	2·1489586	118·16	2·0724710	86·063	1·9348173
·98	140·98	2·1491637	118·27	2·0728946	86·265	1·9358351
·99	141·04	2·1493631	118·33	2·0733119	86·464	1·9368374
1·0	141·11	2·1495607	118·50	2·0737211	86·660	1·9378230

Tables for Use with MM. Ganguillet and Kutter's Formula.

TABLE 49.—VALUES OF $\frac{l}{n}$ FOR DIFFERENT DEGREES OF ROUGHNESS VARYING FROM $n = ·0070$ TO ·050.

n	$\frac{l}{n}$	n	$\frac{l}{n}$	n	$\frac{l}{n}$	n	$\frac{l}{n}$
0·0070	258·76	0·0130	139·33	0·0190	95·33	0·0290	62·46
0·0075	241·51	0·0135	134·17	0·0195	92·89	0·0300	60·38
0·0080	226·41	0·0140	129·38	0·0200	90·57	0·0320	56·60
0·0085	213·10	0·0145	124·92	0·0205	88·35	0·0340	53·27
0·0090	201·26	0·0150	120·75	0·0210	85·25	0·0360	50·31
0·0095	190·67	0·0155	116·86	0·0220	82·33	0·0380	47·67
0·0100	181·13	0·0160	113·21	0·0230	78·75	0·0400	45·28
0·0105	172·51	0·0165	115·78	0·0240	75·47	0·0420	43·13
0·0110	164·67	0·0170	106·55	0·0250	72·45	0·0440	41·17
0·0115	157·51	0·0175	103·50	0·0260	69·67	0·0460	39·38
0·0120	150·94	0·0180	100·63	0·0270	67·09	0·0480	37·74
0·0125	144·91	0·0185	97·91	0·0280	64·69	0·0500	36·23

TABLE 50.—TABLE OF VALUES OF S, $\sqrt{S}$ AND $\left(a + \frac{m}{S}\right)$ FOR OPEN AND CLOSED CHANNELS, FOR VARIOUS INCLINATIONS

Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$
1	5280·	1·0	1·0	41·66327	77	68·57	·012987013	·113961	41·87665
2	2640·	·5	·707106	41·66608	78	67·69	·012820513	·113228	41·87945
3	1760·	·333333333	·577350	41·66890	79	66·84	·012658228	·112509	41·88226
4	1320·	·25	·5	41·67169	80	66·	·0125	·111803	41·88507
5	1056·	·2	·447214	41·67451	81	65·18	·012345679	·111111	41·88787
6	880·	·166666666	·408248	41·67773	82	64·39	·012195122	·110431	41·89067
7	754·3	·142857143	·377978	41·68012	83	63·62	·012048193	·109764	41·89348
8	660·	·125	·353553	41·68293	84	62·80	·011904762	·109109	41·89629
9	586·7	·111111111	·333333	41·68574	85	62·12	·011764706	·108465	41·89911
10	528·	·1	·316228	41·68854	86	61·40	·011627907	·107833	41·90191
11	480·	·090909090	·301511	41·69135	87	60·69	·011494253	·107211	41·90472
12	440·	·083333333	·288675	41·69416	88	60·	·011363636	·106600	41·90753
13	406·2	·076923077	·277350	41·69696	89	59·32	·011235955	·106000	41·91034
14	377·1	·071428571	·267261	41·69977	90	58·66	·011111111	·105409	41·91314
15	352·	·066666667	·258199	41·70258	91	59·02	·010989011	·104828	41·91595
16	330·	·0625	·25	41·70538	92	57·39	·010869565	·104257	41·91896
17	310·6	·058823529	·242536	41·70819	93	56·78	·010752688	·103695	41·92157
18	293·3	·055555555	·235702	41·71100	94	56·17	·010638298	·103142	41·92437
19	277·9	·052631579	·229416	41·71382	95	55·58	·010526316	·102598	41·92717
20	264·	·05	·223607	41·71662	96	55·	·010416667	·102062	41·92998
21	251·4	·047619048	·218218	41·71942	97	54·43	·010309278	·101535	41·93279
22	240·	·045454545	·213200	41·72223	98	53·88	·010204082	·101015	41·93561
23	229·6	·043478261	·208514	41·72504	99	53·34	·010101010	·100504	41·93841
24	220·	·041666667	·204124	41·72785	100	52·8	·010	·1	41·94122
25	211·2	·04	·2	41·73065	101	52·28	·009900990	·099504	41·94403
26	203·1	·038461538	·196116	41·73346	102	51·76	·009803922	·099015	41·94684
27	195·6	·037037037	·192450	41·73627	103	51·26	·009708738	·098533	41·94964
28	188·6	·035714286	·188982	41·73908	104	50·77	·009615385	·098058	41·95245
29	182·1	·034452759	·185695	41·74188	105	50·29	·009523810	·097590	41·95526
30	176·	·033333333	·182574	41·74469	106	49·81	·009433962	·097129	41·95807
31	170·3	·032258065	·179605	41·74750	107	49·35	·009345794	·096674	41·96087
32	165·	·03125	·176777	41·75030	108	48·89	·009259259	·096225	41·96367
33	160·	·030303030	·174077	41·75312	109	48·44	·009174312	·095783	41·96648
34	155·3	·029411765	·171499	41·75592	110	48·	·009090909	·095346	41·96929
35	150·9	·028571429	·169031	41·75873	111	47·57	·009009009	·094916	41·97209

36	146·7	·027777778	·166667	41·76154	112	47·14	·008928571	·094491	41·97491
37	142·7	·027027027	·164399	41·76434	113	46·72	·008849558	·094072	41·97773
38	138·9	·026315789	·162221	41·76718	114	46·31	·008771930	·093659	41·98053
39	135·4	·025641026	·160125	41·76995	115	45.91	·008695692	·093250	41·98333
40	132·	·025	·158114	41·77277	116	45·52	·008620690	·092848	41·98614
41	128·8	·024390244	·156174	41·77557	117	45·13	·008547009	·092450	41·98895
42	125·7	·023809524	·154303	41·77838	118	44·75	·008474576	·092057	41·99176
43	122·8	·023255814	·152499	41·78119	119	44·37	·008400361	·091669	41·99456
44	120·	·022727273	·150756	41·78401	120	44·	·008333333	·091287	41·99737
45	117·3	·022222222	·149071	41·78679	121	43·64	·008264463	·090909	42·00017
46	114·8	·021739130	·147444	41·78961	122	43·28	·008196721	·090536	42·00298
47	112·3	·021276600	·145865	41·79242	123	42·93	·008130081	·090167	42·00579
48	110·	·020833333	·144337	41·79523	124	42·58	·008064516	·089803	42·00859
49	107·8	·020408163	·142857	41·79804	125	42·24	·008	·089442	42·01141
50	105·6	·02	·141421	41·80084	126	41·91	·007836508	·080987	42·01422
51	103·5	·019607843	·140028	41·80364	127	41·58	·007874016	·088736	42·01702
52	101·5	·019230769	·138676	41·80646	128	41·25	·0078125	·088388	42·01983
53	99·62	·018867925	·137361	41·80927	129	40·93	·007751938	·088045	42·02264
54	97·78	·018518519	·136085	41·81207	130	40·62	·007692308	·087706	42·02545
55	96·	·018181818	·134839	41·81487	131	40·31	·007633588	·087370	42·02825
56	94·29	·017850143	·133630	41·81768	132	40·	·007575758	·087039	42·03106
57	92·65	·017543860	·132453	41·82049	133	39·70	·007518797	·086711	42·03387
58	91·03	·017241379	·131305	41·82329	134	39·40	·007462687	·086387	42·03667
59	89·49	·016949153	·130189	41·82611	135	39·11	·007407407	·086066	42·03945
60	88·	·016666667	·129100	41·82892	136	38·82	·007352941	·085749	42·04228
61	86·56	·016393443	·128037	41·83173	137	38·54	·007299270	·085436	42·04509
62	85·16	·016129032	·127000	41·83453	138	38·26	·007246377	·085126	42·04791
63	83·81	·015873016	·126988	41·83734	139	37·98	·007194245	·084819	42·05072
64	82·50	·015625	·125	41·84015	140	37·71	·007142857	·084516	42·05352
65	81·23	·015384615	·124035	41.84296	141	37·45	·007092199	·084215	42·05633
66	80·	·015151515	·123091	41·84576	142	37·18	·007042254	·083918	42·05914
67	78·81	·014925353	·122169	41·84857	143	36·92	·006993007	·083624	42·06195
68	77·65	·014705882	·121286	41·85137	144	36·67	·006944444	·083333	42·06475
69	76·52	·014492754	·120386	41·85418	145	36·41	·006896552	·083046	42·06756
70	75·43	·014285714	·119524	41·85698	146	36·16	·006849315	·082760	42·07037
71	74·36	·014084507	·118678	41·85979	147	35·92	·006802721	·082479	42·07317
72	73·33	·013888889	·117851	41·86261	148	35·68	·006756757	·082199	42·07597
73	72·33	·013688630	·117041	41·86542	149	35·44	·006711409	·081923	42·07878
74	71·35	·013513514	·116248	41·86822	150	35·20	·006666667	·081650	42·08159
75	70·40	·013333333	·115470	41·87103	151	34·97	·006622517	·081379	42·08441
76	69·47	·013157895	·114708	41·87384	152	34·74	·006578947	·081111	42·08742

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$
153	34·51	·006535948	·080845	42·09012	350	15·09	·002857143	·053452	42·64311
154	34·29	·006493506	·080582	42·09283	355	15·87	·002816901	·053074	42·65715
155	34·06	·006451613	·080322	42·09564	360	14·67	·002777778	·052705	42·67117
156	33·85	·006410256	·080065	42·09844	365	14·47	·002739726	·052342	42·68516
157	33·63	·006369427	·079809	42·10125	370	14·27	·002702703	·051988	42·69917
158	33·42	·006329114	·079556	42·10406	375	14·08	·002666667	·051640	42·71327
159	33·21	·006289308	·079305	42·10687	380	13·90	·002631579	·051299	42·72727
160	33·	·00625	·079057	42·10967	385	13·71	·002597403	·050965	42·74137
161	32·8	·006211180	·078811	42·11247	390	13·54	·002564103	·050637	42·75537
162	32·59	·006172840	·078568	42·11528	395	13·37	·002531646	·050315	42·76937
163	32·39	·006134969	·078326	42·11809	400	13·20	·002500000	·050000	42·78347
164	32·20	·006097561	·078087	42·12089	405	13·04	·002469136	·049690	42·79747
165	32·	.006060606	·077850	42·12371	410	12·88	·002439024	·049387	42·81147
166	31·81	·006024096	·077615	42·12652	415	12·72	·002409639	·049088	42·82557
167	31·62	·005988024	·077382	42·12933	420	12·57	·002380952	·048795	42·83957
168	31·43	·005952351	·077152	42·13213	425	12·42	·002352941	·048507	42·85387
169	31·24	·005917160	·076923	42·13493	430	12·28	·002325581	·048224	42·86767
170	31·06	·005882353	·076697	42·13775	435	12·14	·002298851	·047946	42·88167
171	30·88	·005847953	·076472	42·14056	440	12·	·002272727	·047673	42·89577
172	30·7	·005813953	·076249	42·14336	445	11·87	·002247191	·047404	42·90977
173	30·52	·005780347	·076029	42·14617	450	11·73	·002222222	·047140	42·92377
174	30·34	·005747126	·075810	42·14897	455	11·60	·002197802	·046880	42·93787
175	30·17	·005714286	·075593	42·15178	460	11·48	·002173913	·046625	42·95187
176	30·	·005681818	·075378	42·15458	465	11·35	·002150538	·046374	42·96597
177	29·83	·005649718	·075164	42·15739	470	11·24	·002127660	·046126	42·97997
178	29·66	·005617978	·074953	42·16021	475	11·12	·002105263	·045883	42·99397
179	29·50	·005586592	·074744	42·16302	480	11·	·002083333	·045644	43·00807
180	29·33	·005555556	·074536	42·16582	485	10·89	·002061856	·045407	43·02207
181	29·17	·005524862	·074329	42·16863	490	10·78	·002040816	·045175	43·03607
182	29·01	·005494505	·074125	42·17144	495	10·67	·002020202	·044947	43·05017
183	28·85	·005464481	·073922	42·17425	500	10·56	·002000000	·044721	43·06417
184	28·70	·005434783	·073721	42·17706	505	10·46	·001980198	·044499	43·07827
185	28·54	·005405405	·073521	42·17986	510	10·35	·001960784	·044281	43·09227
186	28·39	·005376344	·073324	42·18267	515	10·25	·001941748	·044065	43·10627
187	28·24	·005347594	·073127	42·18547	520	10·15	·001923077	·043853	43·12037
188	28·09	·005319149	·072932	42·18828	525	10·06	·001904763	·043644	43·13437

189	27·94	·005291005	·072739	42·19109	530	9·962	·001886792	·043437	43·14847
190	27·79	·005263158	·072548	42·19389	535	9·870	·001869159	·043234	43·16247
191	27·64	·005235602	·072357	42·19671	540	9·778	·001851852	·043033	43·17647
192	27·50	·005208333	·072169	42·19952	545	9·688	·001834862	·042835	43·19057
193	27·36	·005181347	·071982	42·20232	550	9·600	.001818182	·042640	43·20457
194	27·22	·005154639	·071796	42·20513	555	9·513	·001801802	·042448	43·21857
195	27·08	·005128205	·071612	42·20794	560	9·428	·001785714	·042258	43·23267
196	26·94	·005102041	·071429	42·21075	565	9·345	·001769912	·042070	43·24677
197	26·80	·005076142	·071247	42·21355	570	9·263	·001754386	·041885	43·26077
198	26·67	·005050505	·071067	42·21636	575	9·182	·001739130	·041703	43·27477
199	26·53	·005025126	·070888	42·21917	580	9·103	·001724138	·041523	43·28877
200	26·40	·005	·070710	42·22197	585	9·026	·001709420	·041345	43·30287
205	25·76	·004878049	·069843	42·23601	590	8·949	·001694915	·041169	43·31687
210	25·14	·004761905	·069007	42·25005	595	8·874	·001680672	·040096	43·33087
215	24·56	·004651163	·068199	42·26408	600	8·800	·001666667	·040825	43·34497
220	24·	·004545454	·067419	42·27813	605	8·727	·001652893	·040656	43·35897
225	23·47	·004444444	·066667	42·29216	610	8·656	·001639344	·040489	43·37307
230	22·96	·004347826	·065938	42·30619	615	8·585	·001626016	·040324	43·38707
235	22·48	·004255319	·065233	42·32024	620	8·516	·001612903	·040161	43·40107
240	22·	·004166667	·064549	42·33427	625	8·448	·001600000	·040000	43·41517
245	21·55	·004081623	·063885	42·34832	630	8·338	·001587302	·039841	43·42917
250	21·12	·004000000	·063246	42·36235	635	8·317	·001574803	·039684	43·44317
255	20·71	·003921569	·062620	42·37638	640	8·250	·001562500	·039528	43·45727
260	20·31	·003846154	·062018	42·39043	645	8·186	·001550388	·039375	43·47127
265	19·92	·003773585	·061430	42·40447	650	8·123	·001538462	·039223	43·48537
270	19·56	·003703704	·060858	42·41849	655	8·061	·001526718	·039073	43·49937
275	19·20	·003633634	·060302	42·43254	660	8·	·001515152	·038925	43·51337
280	18·86	·003571429	·059761	42·44657	665	7·940	·001503759	·038778	43·52747
285	18·53	·003508772	·059235	42·46062	670	7·881	·001492537	·038633	43·54147
290	18·20	·003448276	·058722	42·47466	675	7·822	·001481481	·038490	43·55547
295	17·90	·003389831	·058222	42·48868	680	7·765	·001470588	·038348	43·56997
300	17·60	·003333333	·057735	42·50273	685	7·708	·001459854	·038208	43·58357
305	17·31	·003278689	·057260	42·51675	690	7·652	·001449275	·038069	43·59767
310	17·03	·003225806	·056796	42·53081	695	7·597	·001438849	·037932	43·61167
315	16·76	.003174603	·056344	42·54484	700	7·543	·001428571	·037796	43·62567
320	16·50	·003125000	·055902	42·55887	705	7·490	·001418440	·037662	43·63977
325	16·25	·003076923	·055470	42·57292	710	7·437	·001408451	·037529	43·65377
330	16·	·003030303	·055048	42·58696	715	7·385	·001398601	·037398	43·66787
335	15·76	·002985075	·054636	42·60099	720	7·333	·001388889	·037268	43·68187
340	15·53	·002941176	·054232	42·61503	725	7·283	·001379310	·037139	43·69587
345	15·30	·002898551	·053838	42·62907	730	7·233	·001369863	·037012	43·70997

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S.	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S.	$\sqrt{S}$	$a + \frac{m}{S}$
735	7·184	·001360544	·036885	43·72397	1120	4·714	·000892857	·029881	44·80477
740	7·135	·001351351	·036761	43·73797	1125	4·693	·000888888	·029814	44·81887
745	7·087	·001342282	·036637	43·75207	1130	4·673	·000884956	·029748	44·83297
750	7·040	·001333333	·036515	43·76607	1135	4·652	·000881057	·029683	44·84697
755	6·993	·001324503	·036394	43·78017	1140	4·632	·000817193	·029617	44·86107
760	6·948	·001315789	·036274	43·79417	1145	4·611	·000873365	·029553	44·87507
765	6·902	·001307190	·036155	43·80817	1150	4·591	·000869566	·029488	44·88907
770	6·857	·001298701	·036038	43·82227	1155	4·571	·000865801	·029425	44·90317
775	6·812	·001290323	·035921	43·83627	1160	4·552	·000862069	·029361	44·91717
780	6·769	·001282051	·035806	43·85027	1165	4·532	·000858370	·029298	44·93117
785	6·726	·001273885	·035691	43·86437	1170	4·513	·000854701	·029235	44·94527
790	6·684	·001265823	·035578	43·87837	1175	4·494	·000851064	·029173	44·95907
795	6·642	·001257862	·035466	43·89247	1180	4·475	·000847458	·029111	44·97337
800	6·600	·001250000	·035355	43·90647	1185	4·456	·000843882	·029049	44·98737
805	6·559	·001242236	·035245	43·92047	1190	4·437	·000840336	·028988	45·00137
810	6·518	·001234568	·035136	43·93457	1195	4·418	·000836820	·028928	45·01547
815	6·478	·001226994	·035028	43·94857	1200	4·400	·000833333	·028868	45·02947
820	6·439	·001219512	·034922	43·96257	1205	4·382	·000829875	·028808	45·04357
825	6·400	·001212121	·034816	43·97687	1210	4·364	·000826446	·028689	45·05757
830	6·362	·001204819	·034710	43·99067	1215	4·346	·000823045	·028689	45·07157
835	6·324	·001197605	·034606	44·00477	1220	4·328	·000819672	·028630	45·08567
840	6·286	·001190476	·034503	44·01877	1225	4·310	·000816326	·028571	45·09967
845	6·248	·001183432	·034401	44·03277	1230	4·293	·000813008	·028513	45·11387
850	6·212	·001176471	·034300	44·04687	1235	4·275	·000809717	·028455	45·12777
855	6·175	·001169591	·034199	44·06087	1240	4·258	·000806452	·028398	45·14177
860	6·140	·001162791	·034099	44·07487	1245	4·241	·000803213	·028341	45·15587
865	6·104	·001156069	·034001	44·08897	1250	4·224	·000800000	·028284	45·16987
870	6·069	·001149425	·033903	44·10297	1255	4·207	·000796813	·028228	45·18387
875	6·034	·001142857	·033806	44·11707	1260	4·190	·000793651	·028172	45·19797
880	6·	·001136364	·033710	44·13107	1265	4·174	·000790514	·028116	45·21197
885	5.966	·001129944	·033614	44·14507	1270	4·157	·000787402	·028061	45·22597
890	5·932	·001123596	·033520	44·15917	1275	4·141	·000784314	·028006	45·24007
895	5·900	·001117318	·033426	44·17317	1280	4·129	·000781250	·027951	45·25407
900	5·867	·001111111	·033333	44·18717	1285	4·109	·000778210	·027896	45·26817
905	5·834	·001104972	·033241	44·20127	1290	4·093	·000775116	·027841	45·28217
910	5·802	·001100110	·033108	44·21527	1295	4·077	·000772201	·027789	45·29617

915	5·770	·001093896	·033059	44·22937	1300	4·062	·000769231	·027735	45·31027
920	5·739	·001086957	·032969	44·24337	1305	4·046	·000766283	·027682	45·32427
925	5·708	·001081081	·032879	44·25737	1310	4·031	·000763359	·027629	45·33827
930	5·677	·001075269	·032791	44·28547	1315	4·015	·000760456	·027576	45·35237
935	5·648	·001069519	·032703	44·28547	1320	4·	·000757576	·027524	45·36637
940	5·617	·001063830	·032616	44·29957	1325	3·985	·000754717	·027472	45·38047
945	5·587	·001058201	·032530	44·31357	1330	3·970	·000751880	·027420	45·39447
950	5·558	·001052632	·032444	44·32757	1335	3·955	·000749064	·027369	45·40847
955	5·528	·001047120	·032359	44·34167	1340	3·940	·000746268	·027318	45·42257
960	5·500	·001041667	·032275	44·35567	1345	3·926	·000743420	·027276	45·43657
965	5·472	·001036269	·032191	44·36967	1350	3·911	·000740741	·027217	45·45057
970	5·434	·001030928	·032108	44·38377	1355	3·897	·000738007	·027166	45·46467
975	5·415	·001025641	·032026	44·39777	1360	3·882	·000735294	·027116	45·47867
980	5·388	·001020408	·031944	44·41187	1365	3·868	·000732601	·027067	45·49277
985	5·360	·001015228	·031863	44·42587	1370	3·854	·000729927	·027017	45·50377
990	5·333	·001010101	·031782	44·43987	1375	3·840	·000727273	·026968	45·52077
995	5·306	·001005025	·031702	44·45397	1380	3·826	·000724638	·026919	45·53487
1000	5·280	·001000000	·031623	44·46797	1385	3·812	·000722022	·026870	45·54887
1005	5·253	·000985025	·031544	44·48197	1390	3·799	·000719424	·026822	45·56297
1010	5·228	·00099099	·031466	44·49607	1395	3·785	·000716846	·026774	45·57697
1015	5·202	·000985222	·031388	44·51007	1400	3·771	·000714286	·026726	45·59097
1020	5·176	·000980392	·031311	44·52417	1405	3·758	·000711744	·026679	45·60507
1025	5·151	·000975610	·031235	44·53817	1410	3·745	·000709220	·026631	45·61907
1030	5·126	·000970873	·031159	44·55217	1415	3·731	·000706714	·026584	45·63307
1035	5·101	·000966184	·031083	44·56627	1420	3·718	·000704225	·026537	45·64717
1040	5·077	·000961538	·031009	44·58027	1425	3·705	·000701754	·026491	45·66117
1045	5·053	·000956938	·030934	44·59427	1430	3·692	·000699300	·026444	45·67527
1050	5·029	·000952381	·030861	44·60837	1435	3·680	·000696864	·026398	45·68927
1055	5·005	·000947867	·030787	44·62237	1440	3·667	·000694444	·026352	45·70327
1060	4·981	·000943396	·030715	44·63647	1445	3·654	·000992042	·026307	45·71737
1065	4·958	·000938967	·030643	44·65047	1450	3·641	·000689655	·026261	45·73137
1070	4·935	·000934579	·030571	44·66447	1455	3·629	·000687285	·026216	45·74537
1075	4·912	·000930233	·030499	44·67857	1460	3·617	·000684931	·026171	45·75947
1080	4·889	·000925926	·030429	44·69257	1465	3·604	·000682594	·026126	45·77347
1085	4·866	·000921659	·030359	44·70657	1470	3·592	·000680272	·026082	45·78757
1090	4·844	·000917431	·030289	44·72067	1475	3·580	·000677966	·026038	45·80157
1095	4·822	·000913242	·030220	44·73467	1480	3·568	·000675676	·025994	45·81557
1100	4·800	·000909090	·030151	44·74877	1485	3·556	·000673401	·025950	45·82967
1105	4·778	·000904159	·030069	44·76277	1490	3·544	·000671141	·025907	45·84367
1110	4·757	·000900900	·030015	44·77677	1495	3·532	·000668896	·025863	45·85767
1115	4·735	·000896861	·029948	44·79087	1500	3·520	·000666666	·025820	45·87177

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S.	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S.	$\sqrt{S}$	$a + \frac{m}{S}$
1505	3·508	·000664452	·025777	45·88577	1890	2·794	·000529101	·023002	46·96667
1510	3·497	·000662252	·025734	45·89987	1895	2·786	·000527705	·022972	46·98077
1515	3·485	·000660066	·025691	45·91387	1900	2·779	·000526316	·022942	46·99477
1520	3·474	·000657895	·025649	45·92787	1905	2·772	.000524934	·022911	47·00877
1525	3·462	·000655737	·025607	45·94197	1910	2,764	·000523560	·022881	47·02287
1530	3·451	·000653595	·025566	45·95597	1915	2·757	·000522193	·022852	47·03687
1535	3·440	·000652117	·025524	45·96997	1920	2·750	·000520833	·022822	47·05097
1540	3·429	·000649351	·025482	45·98407	1925	2·743	·000519481	·022792	47·06497
1545	3·417	·000647275	·025441	45·99807	1930	2·736	·000518135	·022763	47·07897
1550	3·407	·000645161	·025400	46·01217	1935	2·729	·000516796	·022733	47·09307
1555	3·396	·000643087	·025359	46·02617	1940	2·722	·000515464	·022704	47·10707
1560	3·385	·000641025	·025318	46·04017	1945	2·715	·000514139	·022675	47·12107
1565	3·374	·000638978	·025278	46·05427	1950	2·708	·000512821	·022646	47·13517
1570	3·363	·000636943	·025238	46·06827	1955	2·701	·000511509	·022616	47·14917
1575	3·352	·000634921	·025198	46·08227	1960	2·694	·000510204	·022588	47·16327
1580	3·342	·000632911	·025158	46·09637	1965	2·687	·000508906	·022559	47·17727
1585	3·331	·000630915	·025118	46·11037	1970	2·680	·000507614	·022530	47·19127
1590	3·321	·000628931	·025078	46·12447	1975	2·673	·000506329	·022502	47·20537
1595	3·310	·000626959	·025039	46·13847	1980	2·667	·000505051	·022473	47·21937
1600	3·300	·000625000	·025000	46·15247	1985	2·660	·000503778	·022445	47·23337
1605	3·290	·000623053	·024961	46·16657	1990	2·653	·000502513	·022417	47·24747
1610	3·280	·000621118	·024922	46·18057	1995	2·647	·000501253	·022388	47·26147
1615	3·260	·000619195	·024884	46·19457	2000	2·640	·000500000	·022361	47·27557
1620	3·259	·000617284	·024845	46·20887	2005	2·633	·000498753	·022333	47·28957
1625	3·249	·000615384	·024807	46·22267	2010	2·627	·000497512	·022305	47·30357
1630	3·239	·000613497	·024769	46·23677	2015	2·620	·000496278	·022277	47·31767
1635	3·229	·000611621	·024731	46·25077	2020	2·614	·000495050	·022250	47·33167
1640	3·220	·000699756	·024693	46·26477	2025	2·607	·000493827	·022222	47·34567
1645	3·210	·000607900	·024656	46·27887	2030	2·601	·000492611	·022195	47·35977
1650	3·200	·000606060	·024618	46·29287	2035	2·595	·000491400	·022168	47·37377
1655	3·190	·000604230	·024581	46·30697	2040	2·588	·000490196	·022140	47·38787
1660	3·181	·000602409	·024544	46·32097	2045	2·582	·000488998	·022113	47·40187
1665	3·171	·000600601	·024507	46·33497	2050	2·576	·000487805	·022086	47·41587
1670	3·162	·000598802	·024470	46·34907	2055	2 569	·000486618	·022059	47·42997
1675	3·152	·000597015	·024434	46·36317	2060	2·563	·000485437	·022033	47·44397
1680	3·143	·000595238	·024398	46·37707	2065	2·557	·000484213	·022005	47·45807

1685	3·134	·000593102	·024354	46·39117	2070	2·551	·000483093	·021979	47·47207
1690	3·124	·000591717	·024325	46·40517	2075	2 545	·000481928	·021953	47·48607
1695	3·115	·000589971	·024290	46·41927	2080	2·538	·000480769	·021926	47·50017
1700	3·106	·000588235	·024254	46·43327	2085	2·532	·000479616	·021900	47·51417
1705	3·097	·000586510	·024218	46·44727	2090	2·526	·000478469	·021874	47·52817
1710	3·008	·000584795	·024183	46·46137	2095	2·520	·000477327	·021848	47·54227
1715	3·079	.000583090	·024147	46·47537	2100	2·514	·000476190	·021822	47·55627
1720	3.070	·000581395	·024112	46·48937	2105	2·508	·000475059	·021796	47·57037
1725	3·061	·000579710	·024077	46·50347	2110	2·502	·000473934	·021770	47·58437
1730	3·052	·000578035	·024042	46·51747	2115	2·496	·000472813	·021744	47·59837
1735	3·042	·000576369	·024008	46·53157	2120	2·491	·000471698	·021719	47·61247
1740	3·035	·000574712	·023973	46·54557	2125	2·485	·000470588	·021693	47·62647
1745	3·026	·000573066	·023939	46·55957	2130	2·479	·000469484	·021668	47·64047
1750	3·017	·000571429	·023905	46·57367	2135	2·473	·000468384	·021642	47·65457
1755	3·009	·000569801	·023871	46·58767	2140	2 467	·000467290	·021617	47·66857
1760	3·	·000568128	·023837	46·60187	2145	2·462	·000466200	·021592	47·68267
1765	2·992	·000566572	·023803	46·61577	2150	2·456	·000465116	·021567	47·69667
1770	2·983	·000564972	·023769	46·62977	2155	2·450	·000464037	·021542	47·71067
1775	2·975	·000563380	·023736	46·64387	2160	2·444	·000462963	·021517	47·72477
1780	2·966	·000561798	·023702	46·65787	2165	2·439	·000461894	·021492	47·73877
1785	2·958	·000560224	·023669	46·67187	2170	2·433	·000460829	·021467	47·75277
1790	2·950	·000558659	·023636	46·68597	2175	2·428	·000459770	·021442	47·76687
1795	2·942	·000557103	·023603	46·69997	2180	2·422	·000458716	·021418	47·78087
1800	2·933	·000555555	·023570	46·71397	2185	2·416	·000457666	·021393	47·79497
1805	2·925	·000554017	·023538	46·72807	2190	2·411	·000456621	·021369	47·80897
1810	2·917	·000552486	·023505	46·74207	2195	2·405	·000455581	·021344	47·82297
1815	2·909	·000550964	·023473	46·75617	2200	2·400	·000454545	·021320	47·83707
1820	2·901	·000549451	·023440	46·77017	2205	2·395	·000453515	·021296	47·85107
1825	2·893	·000547945	·023408	46·78417	2210	2·389	·000452489	·021272	47·86507
1830	2·885	·000546448	·023376	46·79827	2215	2·384	·000451467	·021248	47·87917
1835	2·877	·000544949	·023344	46·81227	2220	2·378	·000450450	·021224	47·89317
1840	2·870	·000543478	·023313	46·82627	2225	2·373	·000449438	·021200	47·90727
1845	2·862	·000542005	·023281	46·84037	2230	2·368	·000448430	·021176	47·92127
1850	2·854	·000540541	·023250	46·85437	2235	2·362	·000447427	·021152	47·93527
1855	2·847	·000539084	·023218	46·86847	2240	2·357	·000446429	·021129	47·94937
1860	2·839	·000537633	·023187	46·88247	2245	2·352	·000445434	·021105	47·96337
1865	2·831	·000536193	·023156	46·89657	2250	2·347	·000444444	·021082	47·97737
1870	2·824	·000534759	·023125	46·91057	2255	2·341	·000443459	·021058	47·99147
1875	2·816	·000533333	·023094	46·92457	2260	2·336	·000442478	·021035	48·00547
1880	2·809	·000531915	·023063	46·93867	2265	2·331	·000441501	·021012	48·01957
1885	2·801	·000530504	·023033	46·95287	2270	2·326	·000440529	·020989	48 03357

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a+\frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a+\frac{m}{S}$
2275	2·321	·000430560	·020966	48·04757	2660	1·985	·000375940	·019389	49·12847
2280	2·316	·000438597	·020943	48·06187	2665	1·981	·000375235	·019371	49·14257
2285	2.311	·000437637	·020920	48·07587	2670	1·977	·000374532	·019353	49·15657
2290	2·306	·000436681	·020897	48·08967	2675	1·974	·000373832	·019334	49·17067
2295	2·301	·000435730	·020874	48·10377	2680	1·970	·000373134	·019316	49·18467
2300	2·296	·000434783	.020853	48·11777	2685	1·966	·000372437	·019298	49·19867
2305	2·291	·000433839	·020829	48·13187	2690	1·963	·000371747	·019281	49·21277
2310	2·286	·000432900	·020806	48·14587	2695	1·959	·000371058	·019263	49·22677
2315	2·281	·000431965	·020784	48·15987	2700	1·956	·000370370	·019245	49·24077
2320	2·276	·000431034	·020761	48·17397	2705	1·952	·000369686	·019228	49·25487
2325	2·271	·000430108	·020740	48·18797	2710	1·949	·000369004	·019004	49·26887
2330	2·266	·000429185	·020717	48·20207	2715	1·945	·000368324	·019192	49·28297
2335	2·261	·000428266	·020694	48·21607	2720	1·941	·000367647	·019174	49·29697
2340	2·256	·000427350	·020672	48·23007	2725	1·938	·000366972	·019156	49·31097
2345	2·252	·000426439	·020650	48·24417	2730	1·934	·000366300	·019139	49·32507
2350	2·247	·000425532	·020628	48·25817	2735	1·931	·000365631	·019121	49·33907
2355	2·242	·000424629	·020607	48·27217	2740	1·927	·000364964	·019104	49·35307
2360	2·237	·000423729	·020585	48·28627	2745	1·923	·000364299	·019086	49·36717
2365	2·233	·000422833	·020563	48·30027	2750	1·920	·000363636	·019069	49·38117
2370	2·228	·000421941	·020541	48·31437	2755	1·916	·000362972	·019052	49·39527
2375	2·223	·000421053	·020520	48·32827	2760	1·913	·000362319	·019035	49·40927
2380	2·219	·000420168	·020498	48·34237	2765	1·010	·000361664	·019017	49·42327
2385	2·214	·000419287	·020477	48·35647	2770	1·906	·000361011	·019000	49·43737
2390	2·209	·000418410	·020455	48·37047	2775	1·903	·000360360	·018983	49·45137
2395	2·205	·000417534	·020434	48·38447	2780	1·900	·000359712	·018966	49·46547
2400	2·200	·000416667	·020412	48·39857	2785	1·896	·000359066	·018949	49·47947
2405	2·195	·000415801	·020391	48·41257	2790	1·892	·000358423	·018932	49·49347
2410	2·191	·000414938	·020370	48·42667	2795	1·889	·000357782	·018915	49·50757
2415	2·186	·000414079	·020349	48·44087	2800	1·886	·000357143	·018898	49·52157
2420	2·182	·000413223	·020328	48·45467	2805	1·882	·000356506	·018881	49·53557
2425	2·177	·000412371	·022307	48·46877	2810	1·879	·000355871	·018865	49·54987
2430	2·173	·000411523	·020286	48·48277	2815	1·875	·000355279	·018848	49·56387
2435	2·168	·000410678	·020265	48·49677	2820	1·872	·000354610	·018831	49·57777
2440	2·164	·000409836	·020244	48·51087	2825	1·169	·000353982	·018814	49·59177
2445	2·160	·000408998	·020224	48·52487	2830	1·866	·000353357	·018797	49·60577
2450	2·155	·000408163	·020203	48·53897	2835	1·862	·000352733	·018781	49·61987

2455	2·151	·000407332	·020182	48·55279	2840	1·859	·000352113	·018764	49·63387
2460	2·146	·000406504	·020162	48·56697	2845	1·856	·000351423	·018746	49·64787
2465	2·142	·000405680	·020141	48·58107	2850	1·852	·000350877	·018731	49·66197
2470	2·138	·000404858	·020121	48·59507	2855	1·849	·000350877	·018715	49·67597
2475	2·133	·000404040	·020101	48·60907	2860	1·846	·000349650	·018699	49·69007
2480	2·129	·000403226	·020080	48·62317	2865	1·843	·000349040	·018682	49·70407
2485	2·125	·000402414	·020060	48·63717	2870	1·839	·000348432	·018666	49·71807
2490	2·120	·000401606	·020040	48·65127	2875	1·836	·000347827	·018650	49·73217
2495	2·116	·000400802	·020020	48·66527	2880	1·833	·000347222	·018634	49·74617
2500	2·112	·000400000	·020000	48·67927	2885	1·830	·000346662	·018617	49·76017
2505	2·108	·000399202	·019980	48·69337	2890	1·827	·000346021	·018602	49·77427
2510	2·104	·000398406	·019960	48·70737	2895	1·824	·000345427	·018585	49·78827
2515	2·099	·000397614	·019940	48·72137	2900	1·820	·000344827	·018569	49·80237
2520	2·095	·000396825	·019920	48·73547	2905	1·817	·000344234	·018554	49·81637
2525	2·091	·000396039	·019901	48·74947	2910	1·814	·000343643	·018537	49·83037
2530	2·087	·000395257	·019881	48·76357	2915	1·811	·000343057	·018521	49·84447
2535	2·083	·000394477	·019861	48·77757	2920	1·808	·000342456	·018506	49·85847
2540	2·079	·000393701	·019842	48·79157	2925	1·805	·000341880	·018490	49·87247
2545	2·075	·000392927	·019822	48·80567	2930	1·802	·000341297	·018474	49·88657
2550	2·071	·000392157	·019803	48·81967	2935	1·799	·000340716	·018456	49·90057
2555	2·066	·000391389	·019784	48·83377	2940	1·796	·000340136	·018442	49·91467
2560	2·063	·000390625	·019764	48·84777	2945	1·793	·000339559	·018427	49·92867
2565	2·058	·000389864	·019745	48·86177	2950	1·490	·000338983	·018414	49·94267
2570	2·054	·000389105	·019726	48·87587	2955	1·787	·000338409	·018396	49·95677
2575	2·050	·000388349	·019706	48·88987	2960	1·784	·000337838	·018380	49·97077
2580	2·047	·000387697	·019687	48·90387	2965	1·781	·000337268	·018264	49·98477
2585	2·042	·000386847	·019668	48·91797	2970	1·778	·000336700	·018349	49·99887
2590	2·039	·000386100	·019649	48·93197	2975	1·775	·000336134	·018334	50·01287
2595	2·035	·000385357	·019630	48·94607	2980	1·772	·000335571	·018319	50·02697
2600	2·031	·000384615	·019612	48·96007	2985	1·769	·000335008	·018303	50·04097
2605	2·027	·000383877	·019593	48·97407	2990	1·766	·000334482	·018288	50·05497
2610	2·023	·000383142	·019574	48·98817	2995	1·763	·000333890	·018272	50·06907
2615	2·019	·000382410	·019555	49·00217	3000	1·760	·000333333	·018257	50·08307
2620	2·015	·000381679	·019536	49·01617	3010	1·754	·000332226	·018227	50·11117
2625	2·011	·000380952	·019518	49·03027	3020	1·748	·000331129	·018197	50·13927
2630	2·008	·000380228	·019499	49·04427	3030	1·742	·000330033	·018667	50·16727
2635	2·004	·000379507	·019481	49·05837	3040	1·737	·000328947	·018137	50·19537
2640	2·	·000378787	·019462	49·07237	3050	1·731	·000327869	·018107	50·22347
2645	1·996	·000378072	·019444	49·08637	3060	1·725	·000326797	·018077	50·25157
2650	1·992	·000377359	·019426	49·10047	3070	1·720	·000325733	·018048	50·27957
2655	1·989	·000376648	·019407	49·11447	3080	1·715	·000324675	·018019	50·30767

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$
3090	1·709	·000323625	·017989	50·33577	4520	1·168	·000221239	·014874	54·35047
3100	1·703	·000322581	·017960	50·36387	4540	1·163	·000220264	·014841	54·40647
3110	1·698	·000321543	·017932	50·39187	4560	1·158	·000219298	·014808	54·46247
3120	1·692	·000320513	·017903	50·41997	4580	1·153	·000218341	·014776	54·51847
3130	1·687	·000319489	·017874	50·44807	4600	1·148	·000217391	·014744	54·57447
3140	1·682	·000318471	·017845	50·47617	4620	1·143	·000216450	·014712	54·63047
3150	1·676	·000317460	·017817	50·50417	4640	1·138	·000215517	·014681	54·68747
3160	1·671	·000316456	·017789	50·53227	4660	1·133	·000214592	·014649	54·74347
3170	1·666	·000315457	·017761	50·56037	4680	1·128	·000213675	·014617	54·79947
3180	1·660	·000314465	·017733	50·58847	4700	1·124	·000212766	·014586	54·85547
3190	1·655	·000313480	·017705	50·61647	4720	1·119	·000211864	·014557	54·91147
3200	1·650	·000312500	·017677	50·64457	4740	1·114	·000210970	·014524	54·96747
3220	1·640	·000310559	·017622	50·70077	4760	1·109	·000210084	·014492	55·02347
3240	1·629	·000308641	·017568	50·75687	4780	1·104	·000209205	·014464	55·08047
3260	1·620	·000306748	·017514	50·81297	4800	1·100	·000208333	·014434	55·13647
3280	1·610	·000304878	·017461	50·86917	4820	1·096	·000207469	·014404	55·19247
3300	1·600	·000303030	·017408	50·92537	4840	1·091	·000206612	·014374	55·24847
3320	1·590	·000301205	·017355	50·98147	4860	1·087	·000205761	·014344	55·30447
3340	1·581	·000299401	·017303	51·03767	4880	1·082	·000204918	·014315	55·36047
3360	1·571	·000297619	·017251	51·03387	4900	1·078	·000204081	·014285	55·41747
3380	1·562	·000295858	·017200	51·14997	4920	1·073	·000203252	·014256	55·47347
3400	1·553	·000294118	·017150	51·20607	4940	1·069	·000202429	·014227	55·52947
3420	1·544	·000292398	·017100	51·26227	4960	1·065	·000201613	·014199	55·58547
3440	1·535	·000290688	·017050	51·31837	4980	1·060	·000200803	·014170	55·64147
3460	1·526	·000289017	·017000	51·37457	5000	1·056	·000200000	·014142	55·69747
3480	1·517	·000287356	·016951	51·43067	5040	1·048	·000198570	·014086	55·81047
3500	1·509	·000285714	·016903	51·48687	5120	1·031	·000195313	·013975	56·03447
3520	1·500	·000284091	·016855	51·54297	5200	1·015	·000192308	·013888	56·25947
3540	1·491	·000282486	·016807	51·59917	5280	1·000	·000189394	·013862	56·48347
3560	1·483	·000280899	·016760	51·65537	5360	·985	·000186567	·013659	56·70847
3580	1·475	·000279329	·016713	51·71147	5440	·971	·000183824	·013558	56·93347
3600	1·467	·000277778	·016667	51·76747	5520	·957	·000181160	·013460	57·15747
3620	1·459	·000276243	·016620	51·82347	5600	·943	·000178572	·013363	57·38247
3640	1·450	·000274725	·016575	51·87947	5680	·930	·000176056	·013268	57·60647
3660	1·442	·000273224	·016530	51·93547	5760	·917	·000173611	·013176	57·83147
3680	1·435	·000271739	·016484	51·99147	5840	·904	·000171233	·013085	58·05647

3700	1·427	·000270270	·016440	52·04747	5920	·892	·000168919	·012997	58·28047
3720	1·420	·000268817	·016395	52·10447	6000	·880	·000166667	·012910	58·50547
3740	1·412	·000267380	·016352	52·16047	6080	·868	·000164474	·012820	58·72947
3760	1·404	·000265958	·016308	52·21647	6160	·857	·000162338	·012741	58·95447
3780	1·397	·000264550	·016265	52·27247	6240	·846	·000160256	·012659	59·17947
3800	1·390	·000263158	·016222	52·32847	6320	·836	·000158228	·012579	59·40347
3820	1·382	·000261780	·016180	52·38447	6400	·825	·000156250	·012500	59·62847
3840	1·375	·000260417	·016138	52·44147	6480	·815	·000154321	·012422	59·85247
3860	1·368	·000259067	·016095	52·49747	6560	·805	·000152439	·012347	60·07747
3880	1·361	·000257732	·016054	52·55347	6640	·795	·000150602	·012272	60·30247
3900	1·354	·000256410	·016013	52·60947	6720	·786	·000148810	·012199	60·52647
3920	1·347	·000255102	·015972	52·66547	6800	·777	·000147059	·012127	60·75147
3940	1·340	·000253807	·015931	52·72147	6880	·767	·000145349	·012056	60·97547
3960	1·333	·000252525	·015891	52·77747	6960	·759	·000143678	·011986	61·20047
3980	1·327	·000251526	·015851	52·83447	7000	·754	·000142857	·011952	61·31347
4000	1·320	·000250000	·015811	52·89047	7040	·750	·000142045	·011919	61·42547
4020	1·313	·000248756	·015772	52·94647	7120	·742	·000140449	·011851	61·64947
4040	1·307	·000247525	·015733	53·01147	7200	·733	·000138889	·011785	61·87447
4060	1·300	·000246306	·015694	53·05847	7280	·725	·000137363	·011720	62·09847
4080	1·294	·000245098	·015655	53·11447	7360	·718	·000135869	·011656	62·32347
4100	1·288	·000243903	·015617	53·17047	7440	·710	·000134408	·011594	62·54847
4120	1·282	·000242718	·015580	53·22747	7500	·704	·000133333	·011547	62·71647
4140	1·275	·000241546	·015542	53·28347	7520	·702	·000132979	·011532	62·77247
4160	1·269	·000240382	·015505	53·33947	7600	·695	·000131579	·011471	62·99747
4180	1·263	·000239235	·015467	53·39547	7680	·687	·000130208	·011411	63·22247
4200	1·257	·000238095	·015430	53·45147	7760	·680	·000128866	·011352	63·44647
4220	1·251	·000236967	·015394	53·50747	7840	·673	·000127551	·011293	63·67147
4240	1·245	·000235849	·015358	53·56447	7920	·667	·000126263	·011237	63·89547
4260	1·239	·000234742	·015322	53·62047	8000	·660	·000125000	·011180	64·12047
4280	1·234	·000233645	·015286	53·67647	8080	·653	·000123763	·011125	64·34547
4300	1·228	·000232558	·015250	53·73247	8160	·647	·000122549	·011070	64·56947
4320	1·222	·000231482	·015215	53·78847	8240	·641	·000121359	·011016	64·79447
4340	1·217	·000230415	·015180	53·84447	8320	·635	·000120192	·010963	65·01847
4360	1·211	·000229716	·015145	53·90047	8400	·629	·000119048	·010911	65·24347
4380	1·205	·000228311	·015110	53·95747	8480	·623	·000117925	·010860	65·46847
4400	1·200	·000227273	·015076	54·01347	8560	·617	·000116823	·010809	65·69247
4420	1·194	·000226244	·015041	54·06947	8640	·611	·000115741	·010759	65·91747
4440	1·189	·000225225	·015007	54·12547	8720	·605	·000114679	·010709	66·14147
4460	1·184	·000224215	·014974	54·18147	8800	·600	·010113636	·010660	66·36647
4480	1·179	·000223214	·014940	54·23747	8880	·595	·000112613	·010612	66·59147
4500	1·173	·000222222	·014907	54·29347	8960	·585	·000111607	·010565	66·81547

TABLE 50—*continued.*

Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$	Sine of Inclination 1 over.	Fall in Feet per Mile.	S	$\sqrt{S}$	$a + \frac{m}{S}$
9000	·587	·000111111	·010541	66·92747	15040	·351	·000066490	·008154	83·88547
9040	·584	·000110620	·010518	67·04047	15120	·349	·000036138	·008133	84·11047
9120	·579	·000109649	·010472	67·26447	15200	·347	·000065790	·008111	84·33447
9200	·574	·000108696	·010427	67·48947	15280	·346	·000065445	·008090	84·55947
9280	·569	·000107759	·010380	67·71447	15360	·344	·000065104	·008069	84·78447
9360	·564	·000106838	·010336	67·93847	15440	·342	·000064767	·008048	85·00847
9440	·559	·000105932	·010293	68·16347	15520	·340	·000064433	·008027	85·23347
9520	·555	·000105042	·010249	68·38747	15600	·339	·000064103	·008007	85·45747
9600	·550	·000104167	·010206	68·61247	15680	·337	·000063776	·007986	85·68247
9680	·545	·000103306	·010164	68·83747	15760	·335	·000063452	·007966	85·90747
9760	·541	·000102459	·010122	69·06147	15840	·333	·000063131	·007946	86·13147
9840	·537	·000101626	·010081	69·28647	15920	·332	·000062814	·007926	86·35647
9920	·532	·000100807	·010040	69·51047	16000	·330	·000062500	·007906	86·58047
10000	·528	·000100000	·010000	69·73547	16080	·328	·000062189	·007886	86·80547
10080	·524	·000099206	·009960	69·96047	16160	·327	·000061881	·007867	87·03047
10160	·520	·000098425	·009921	70·18447	16240	·325	·000061577	·007847	87·25447
10240	·516	·000097656	·009882	70·40947	16320	·324	·000061275	·007828	87·47947
10320	·512	·000096924	·009844	70·63347	16400	·322	·000060976	·007809	87·70347
10400	·508	·000096154	·009806	70·85847	16480	·320	·000060680	·007790	87·92847
10480	·504	·000095420	·009768	71·08347	16560	·319	·000060387	·007771	88·15347
10560	·500	·000094697	·009731	71·30747	16640	·317	·000060096	·007753	88·37747
10640	·496	·000093985	·009695	71·53247	16720	·316	·000059809	·007734	88·60247
10720	·492	·000093284	·009658	71·75647	16800	·314	·000059524	·007715	88·82647
10800	·489	·000092593	·009623	71·98147	16880	·313	·000059242	·007697	89·05147
10880	·485	·000091912	·009587	72·20647	16960	·311	·000058962	·007679	89·27647
10960	·482	·000091241	·009552	72·43047	17000	·311	·000058824	·007670	89·38847
11000	·480	·000090909	·009534	72·54347	17040	·310	·000058686	·007661	89·50047
11040	·478	·000090580	·009518	72·65547	17120	·308	·000058411	·007643	89·72547
11120	·475	·000089928	·009483	72·88047	17200	·307	·000058140	·007625	89·94947
11200	·471	·000089286	·009449	73·10447	17280	·306	·000058146	·007608	90·17447
11280	·468	·000088653	·009416	73·32947	17360	·304	·000057604	·007590	90·39947
11360	·465	·000088028	·009382	73·55347	17440	·303	·000057429	·007573	90·62347
11440	·462	·000087412	·009350	73·77847	17520	·301	·000057078	·007555	90·84847
11520	·458	·000086806	·009317	74·00347	17600	·300	·000056818	·007538	91·07247
11600	·455	·000086207	·009285	74·22747	17680	·299	·000056561	·007520	91·29747
11680	·452	·000085617	·009253	74·45247	17760	·297	·000056306	·007504	91·52247
11760	·449	·000085034	·009221	74·67647	17840	·296	·000056054	·007487	91·74647

11840	·446	·000084459	·009190	74·90147	17920	·295	·000055804	·007470	91·97047
11920	·443	·000083893	·009160	75·12647	18000	·293	·000055555	·007454	92·19547
12000	·440	·000083333	·009129	75·35047	18080	·292	·000055310	·007437	92·42047
12080	·437	·000082782	·009099	75·57547	18160	·291	·000055066	·007421	92·64547
12160	·434	·000082237	·009069	75·79947	18240	·289	·000054825	·007404	92·86947
12240	·431	·000081699	·009039	76·02447	18320	·288	·000054585	·007388	93·09447
12320	·429	·000081169	·009010	76·24947	18400	·287	·000054348	·007372	93·31847
12400	·426	·000080645	·008980	76·47347	18480	·286	·000054112	·007356	93·54347
12480	·423	·000080128	·008951	76·69847	18560	·285	·000053879	·007340	93·76847
12560	·420	·000079618	·008923	76·92247	18640	·283	·000053648	·007324	93·99247
12640	·418	·000079114	·008895	77·14747	18720	·282	·000053419	·007308	94·21747
12720	·415	·000078616	·008867	77·37247	18800	·281	·000053191	·007293	94·44247
12800	·413	·000078125	·008839	77·59647	18880	·280	·000052966	·007278	94·66647
12880	·410	·000077640	·008811	77·82147	18960	·279	·000052742	·007262	94·89147
12960	·407	·000077160	·008784	78·04547	19000	·280	·000052632	·007255	95·00347
13000	·406	·000076923	·008771	78·15847	19040	·277	·000052521	·007246	95·11547
13040	·405	·000076687	·008757	78·27047	19120	·276	·000052301	·007232	95·34047
13120	·402	·000076220	·008730	78·49547	19200	·275	·000052083	·007217	95·56547
13200	·400	·000075758	·008704	78·71947	19280	·274	·000051867	·007202	95·78947
13280	·398	·000075301	·008678	78·94447	19360	·273	·000061653	·007187	96·01447
13360	·395	·000074850	·008651	79·16847	19440	·272	·000051440	·007172	96·23847
13440	·393	·000074405	·008625	79·39347	19520	·271	·000051229	·007157	96·46347
13520	·390	·000073965	·008600	79·61847	19600	·269	·000051020	·007142	96·68847
13600	·388	·000073530	·008575	79·84247	19680	·268	·000050813	·007128	96·91247
13680	·386	·000073100	·008500	80·06747	19760	·267	·000050607	·007114	97·13747
13760	·384	·000072675	·008525	80·29147	19840	·266	·000050403	·007100	97·36147
13840	·382	·000072254	·000500	80·51647	19920	·265	·000050201	·007085	97·58547
13920	·379	·000071839	·008476	80·74147	20000	·264	·000050000	·007071	97·81147
14000	·377	·000071429	·008452	80·96547	20080	·263	·000049800	·007057	98·03547
14080	·375	·000071023	·008428	81·19047	20160	·262	·000049603	·007043	98·26047
14160	·373	·000070622	·008404	81·41447	20240	·261	·000049407	·007029	98·48447
14240	·371	·000070225	·008380	81·63947	20320	·260	·000049212	·007015	98·70947
14320	·369	·000069832	·008357	81·86447	20400	·259	·000049020	·007001	98·93447
14400	·367	·000069445	·008334	82·08847	20480	·258	·000048828	·006987	99·15847
14480	·365	·000069061	·008310	82·31347	20560	·257	·000048638	·006974	99·38347
14560	·363	·000068681	·008288	82·53747	20640	·256	·000048447	·006960	99·60747
14640	·361	·000068306	·008265	82·76247	20720	·255	·000048263	·006947	99·83247
14720	·359	·000067935	·008242	82·98747	20800	·254	·000048077	·006934	100·05747
14800	·357	·000067568	·008220	82·21147	20880	·253	·000047893	·006920	100·28147
14880	·355	·000067204	·008198	83·43647	20960	·252	·000047710	·006907	100·50647
14960	·353	·000066848	·008176	83·66147	21040	·251	·000047529	·006894	100·73047
15000	·352	·000066667	·008165	83·77347	21120	·250	·000047318	·006881	100·95547

TABLE 51.—TABLE GIVING THE VALUE OF (n) FOR DIFFERENT CHANNELS COMPILED FROM KUTTER, JACKSON, AND HERING, BY FLYNN.

$n=$ ·009	Well-planed timber, in perfect order and alignment; otherwise, perhaps ·01 would be suitable.
$n=$ ·010	Plaster in pure cement; planed timber; glazed, coated, or enamelled stoneware and iron pipes; glazed surfaces of every sort in perfect order.
$n=$ ·011	Plaster in cement with one-third sand in good condition; also for iron, cement, and terra-cotta pipes, well joined and in best order.
$n=$ ·012	Unplaned timber, when perfectly continuous on the inside; flumes.
$n=$ ·013	Ashlar and well-laid brickwork; ordinary metal; earthenware and stoneware pipe in good condition, but not new; cement and terra-cotta pipe not well jointed nor in perfect order; plaster and planed wood in imperfect or inferior condition; and, generally, the materials mentioned with $n=$·010, when in imperfect or inferior condition.
$n=$ ·015	Second-class or rough-faced brickwork; well-dressed stonework; foul and slightly tuberculated iron; cement and terra-cotta pipes, with imperfect joints and in bad order; and canvas lining on wooden frames.
$n=$ ·017	Brickwork, ashlar, and stoneware in an inferior condition; tuberculated iron pipes; rubble in cement or plaster, in good order; fine gravel, well rammed, $\frac{1}{2}$ to $\frac{3}{4}$ inches diameter; and, generally, the materials mentioned with $n=$·013 when in bad order and condition.
$n=$ ·020	Rubble in cement in an inferior condition; coarse rubble, rough-set in a normal condition; coarse rubble set dry; ruined brickwork and masonry; coarse gravel, well rammed, from 1 to $1\frac{1}{2}$ inch diameter; canals with beds and banks of very firm, regular gravel, carefully trimmed and rammed in defected places; rough rubble, with bed partially covered with silt and mud; rectangular wooden troughs, with battens on the inside 2 inches apart; trimmed earth in perfect order.
$n=$ ·0225	Canals in earth above the average in order and regimen.
$n=$ ·025	Canals and rivers in earth of tolerably uniform cross-section, slope, and direction, in moderately good order and regimen, and free from stones and weeds.
$n=$ ·0275	Canals and rivers in earth below the average in order and regimen.
$n=$ ·030	Canals and rivers in earth in rather bad order and regimen, having stones and weeds occasionally, obstructed by detritus.
$n=$ ·035	Suitable for rivers and canals with earthen beds in bad order and regimen, and having stones and weeds in great quantities.
$n=$ ·05	Torrents encumbered with detritus.

TABLE 52.—THE FOLLOWING TABLE, GIVING VALUES OF (n) FOR DIFFERENT SURFACES EXPOSED TO THE FLOW OF WATER, IS TAKEN FROM FLYNN. THE DIMENSIONS ARE IN FEET.

R = HYDRAULIC MEAN DEPTH IN FEET.

S = SINE OF SLOPE.

No.	Series of Bazin.	R in feet.	S.	Breadth of water surface in feet.	Depth in feet.	n.
28	Carefully planed plank	0·07	0·0048922	0·328	0·14	0·0096
29	" " "	0·05	0·0152370	0·328	0·079	0·0087
24	In cement, semi-circular.........	0·82	0·0014243	3·28	1·47	0·01005
2	" rectangular	0·49	0·005060	5·9	0·59	0·01040
25	" with one-third sand, semi-circular....................	0·85	0·0013802	3·28	1·61	0·01113
26	Plank, semi-circular...............	0·91	0·0015227	3·6	1·61	0·01195
21	" trapezoidal	0·82	0·0015213	4·6	1·24	0·01255
22	" "	0·65	0·0048751	4·36	0·98	0·01190
23	" triangular, 45°	0·65	0·004655	4·36	1·87	0·0119
6	" rectangular...............	0·65	0·0022136	6·5	0·85	0·13
7	" "	0·52	0·004889	6·5	0·62	0·0119
8	" "	0·46	0·0081629	6·5	0·52	0·0115
9	" "	0·72	0·0014678	6·5	0·91	0·0129
10	" "	0·46	0·0058744	6·5	0·55	0·0117
11	" "	0·42	0·0083805	6·5	0·49	0·0114
18	" "	0·65	0·0045988	3·9	0·91	0·0114
19		0·49	0·0042731	2·6	0·82	0·0114
20		0·32	0·0059829	1·6	0·62	0·0114
	RAMMED GRAVEL :—					
27	$\frac{2}{5}$ to $\frac{4}{5}$ inch thick, semi-circular	0·75	0·0013639	3·28	1·34	0·0163
4	" " " rectangular	0·65	0·0049736	6·0	0·85	0·0170
	BATTENS PLACED :—					
12	$\frac{2}{3}$-inch apart, rectangular	0·75	0·0014678	6·4	1·01	0·0149
13	" " "	0·55	0·0059664	6·4	0·65	0·0147
14	" " "	0·49	0·0088618	6·4	0·59	0·0149
15	2 inches " "	0·95	0·0014678	6·4	1·31	0·0208
16	" " "	0·69	0·0059976	6·4	0·88	0·0211
17		0·63	0·088618	6·4	0·78	0·0215
1·2	Ashlar, rectangular...............	1·77	0·0008400	8·5	3·0	0·0133
3	Brickwork, rectangular	0·55	0·050250	3·0	0·65	0·0129
39	Ashlar	0·59	0·0081	3·9	0·85	0·0129
	RUBBLE :—					
32	Rather damaged, rectangular	0·52	0·10076	5·9	0·63	0·0167
33	" " "	0·65	0·036856	5·9	0·88	0·0170
1·4	" " new, "	0·63	0·060	3·28	0·95	0·0180
1·3	" " " "	0·72	0·029	3·28	1·18	0·0184
1·6	" " " "	0·82	0·014	3·28	1·54	0·0182
1·5	" " " "	0·88	0·0122	3·28	1·60	0·0192
44	With deposits on the bed, rectangular	1·47	0·00032	6·56	2·62	0·0204
46	With deposits on the bed, rectangular	1·31	0·00032	6·56	2·29	0·0210
35	Damaged rubble, trapezoidal...	1·21	0·014221	4·9	2·29	0·0220

TABLE 52—*continued.*

No.	Series of Bazin.	R in feet.	S	Breadth of water surface in feet.	Depth in feet.	n.
	OTHER OBSERVATIONS :—					
	Gotenbachschale, new rubble, semi-circular	0·32	0·044	5·5	0·59	0·0145
	Grumbachschale, semi-circular, damaged	0·46	0·09927	8·5	0·82	0·0175
	Gerbachschale, semi-circular, much damaged	0·19	0·168	3·7	0·29	0·0185
	Alpbachschale, semi-circular, much damaged	0·72	0·0274	8·2	1·18	0·0230
	Marseilles Canal	2·87	0·00043	19·6	4·4	0·0244
	Jard Canal	1·97	0·0004	19·6	4·4	0·0255
	Chesapeake, Ohio Canal	3·7	0·000698	22·6	7·9	0·0330
	Canal in England	2·43	0·000063	17·7	3·9	0·0184
	Lanter Canal, at Newbury	1·81	0·000664	29·5	1·8	0·0262
	Pannerden Canal, in Holland	10·2	0·000224	558·0	9·8	0·0254
	Canal of Marmels	2·31	0·0005	26·2	2·6	0·0301
	Linth Canal	7·8	0·00034	123·0	10·8	0 0222
	Hübengruben	0·6	0·0013	4·8	0·8	0·0237
	Hockenbach	0·87	0 000787	11·1	1·1	0·0243
	Speyerbach	1·46	0·000667	16·4	1·9	0·0260
	Mississippi	65·6	0·000667	2493·0	16·4	0·0270
	Bayou Plaquemine	16·8	0·00017	275·	25·6	0·0294
	Bayou La Fourche	13·1	0·0004	220·	23·6	0·0200
	Ohio, Point Pleasant	6·7	0·000093	1066·	7·9	0·0210
	Tiber at Rome	9·4	0·00013	239·	14·8	0·0228
	Newka	17·4	0·000015	886·	21·0	0·0252
	Newa	35·4	0·000014	1214·	19·7	0·0262
	Weser	9·5	0·0002	394·	9·8	0·0232
	Elbe	10·9	0·00031	315·	43·6	0·0285
	Rhine, in Holland	12·4	0·00015	1312·	14·7	0·0243
	Seine, at Paris	12·1	0·000137	...	...	0·025
	Seine, at Poissy	13·4	0·00007	...	...	0·028
	Saone, at Raconnay	11·8	0·00004	...	...	0·026
	Haine	5·2	0·0001	...	...	0·028
	CHANNELS OBSTRUCTED BY DETRITUS :—					
	Rhine, at Speyer	9·7	0·000112	1440·	9·7	0·026
	Rhine, at Germersheim	10·8	0·000247	748·	...	0·0227
	Rhine, at Basle	6·9	0·001218	660·	9·1	0·03
	Lech	3·1	0·00115	157·	3·8	0·022
	Saalach	1·4	0·0011	68·	2·1	0·027
	Salzach	4·1	0·0012	38·	11·8	0·028
	Issar	3·9	0·0025	164·	4·4	0·0305
	Escher Canal	4·0	0·003	72·	4·9	0·03
	Plessur	3·5	0·00965	42·	4·6	0·027
	Rhine, at Rhinewald	·79	0·0142	14·	·99	0·031
	Mösa, at Misox	1·2	0·01187	13·	1·3	0·031
	Rhine, at Dornbeschgerthal	1·9	0·0075	16·	2·4	0·035
	Simme, at Leuk	1·6	0·0105	...	...	0·0345

TABLE 53.—VARIATIONS IN VALUE OF (n) (MAXIMUM AND MINIMUM).

Open Channels.		S		n	
Material.	Form.	(Relative values of.)		Min.	Max.
Pure cement	Semi-circular	·0015		·0101	·0104
2 p.c. to 1 fine sand	Ditto	·0015		·0108	·0114
Pure cement	Rectangular	·0049		·0096	·0107
Ditto	Arched invert and curved sides	·00016		·0111	·0114
Planed boards	Semi-circular	·0015		·0117	·0121
Carefully planed boards	Rectangular	·0152	·0047	·0084	·0097
Unplaned boards	Rectangular	·00824	·0015	·0104	·0132
Ditto	Triangular	·0049		·0118	·0124
Ashlar or neatly-jointed brickwork	Usual forms of aqueducts	·00002	·00028	·0103	·0211
Pebbles held in place by cement	Semi-circular	·0015		·0159	·0171
Ditto	Rectangular	·0049		·0170	·0215
Rubble masonry	Rectangular and semi-circular	·0046	·0009	·0138	·0385
Earth with masonry side walls	Rectangular and trapezoidal	·00003	·0022	·0137	·0560
Small rivers and canals	Regular	·0037	·00015	·0106	·0299
Rivers and canals	Irregular	·00011	·0222	·0194	·0550
Pipes under Pressure.					
Material.					
New lead		·3463	·0008	·0067	·0090
Earthenware		·0025		·0111	
Wrought iron		·3055	·0008	·0067	·0160
Ditto galvanized		·0076	·1130	·0077	·0082
New cast iron		·00001	·00094	·0080	·0134
Ditto force main		·00088	·00046	·0110	·0132
Old cast iron		·00025	·03239	·0095	·0292
Ditto force main		·00922	·00105	·0149	·0342
Brickwork (inverted syphon)		·00051	·00007	·0138	·0199

TABLE 54.—VARIATIONS IN VALUE OF (n) (AVERAGE) ACCORDING TO ALBERT WOLLHEIM, A.M.I.C.E.

Material of Sewer.	Condition of Surface.			
	Perfect.	Good.	Fair.	Bad.
Glazed stoneware pipe	·010	·011	·013	·015
Brickwork, ordinary	·012	·013	·015	·017
Ditto, glazed	·011	·012	·013	·014
Rendering, cement mortar	·011	·012	·013	·015
Ditto, neat cement	·010	·011	·012	·013
Ashlar, dressed	·013	·014	·015	·017
Iron (cast), uncoated	·012	·013	·014	·015
Ditto (wrought) and steel	·011	·012	·013	·014

TABLE 55.—VALUES OF $\sqrt{\frac{1}{s}}$ FOR VARIOUS SLOPES.

s	$\sqrt{\frac{1}{s}}$	s	$\sqrt{\frac{1}{s}}$	s	$\sqrt{\frac{1}{s}}$
·000025	200·00	·001$\dot{6}$	24·49	·0200	7·07
·000030	182·57	·00181	23·45	·0$\dot{2}$	6·70
·000040	158·11	·00200	22·36	·0250	6·32
·000050	141·42	·00$\dot{2}$	21·21	·0285	5·91
·000060	129·09	·00250	20·00	·0$\dot{3}$	5·47
·000075	115·47	·00285	18·70	·0400	5·00
·000100	100·00	·00$\dot{3}$	17·32	·0500	4·47
·000120	91·28	·004	15·81	·0$\dot{5}$	4·24
·000150	81·46	·005	14·14	·0$\dot{6}$	3·87
·000200	70·70	·00$\dot{6}$	12·25	·08$\dot{3}$	3·46
·000300	57·73	·01000	10·00	·1000	3·16
·000500	44·72	·01052	9·74	·$\dot{1}$	2·96
·001000	31·62	·0$\dot{1}$	9·48	·1250	2·82
·001050	30·86	·01176	9·21	·1428	2·64
·00$\dot{1}$	30·00	·01250	8·94	·1$\dot{6}$	2·44
·001176	29·16	·01$\dot{3}$	8·66	·2000	2·23
·001250	28·28	·01428	8·36	·2500	2·00
·001$\dot{3}$	27·38	·01507	8·06	·$\dot{3}$	1·73
·001428	26·45	·016	7·74	·5000	1·41
·001507	25·49	·01$\dot{8}$	7·41	1·0000	1·00

TABLES

OF

VELOCITY AND DISCHARGE

OF

SEWERS, PIPES AND CONDUITS

(CIRCULAR AND EGG-SHAPED)

SPECIALLY COMPUTED BY

GANGUILLET AND KUTTER'S FORMULA

TABLE 56.—Velocity and Discharge of Circular Sewers, Pipes and Conduits Running Full (where $n = \cdot 013$) ... pp. 128—159

N.B.—When flowing *half full* the values given for Q must be reduced by one-half.

TABLE 57.—Velocity and Discharge of Egg-shaped Sewers Running Two-thirds full (where $n = \cdot 015$) ... pp. 160—169

TABLE 58.—Velocity and Discharge of Egg-shaped Sewers, calculated by Flynn's modification of Kutter's formula, for various depths on the invert (where $n = \cdot 013$) pp. 170—173

TABLE 56.—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	5		6		7		8		9		10		11		12		13		14	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	4·522	·0986	4·127	·0900	3·821	·0833	3·574	·0779	3·370	·0735	3·197	·0697	3·048	·0664	2·918	·0636	2·803	·0611	2·701	·0589
3	6·389	·3136	5·832	·2863	5·400	·2650	5·051	·2479	4·762	·2337	4·517	·2217	4·307	·2114	4·123	·2024	3·961	·1944	3·817	·1873
4			7·414	·6470	6·865	·5990	6·421	·5603	6·053	·5283	5·743	·5011	5·475	·4778	5·242	·4574	5·036	·4395	4·853	·4235
5							7·709	1·051	7·268	·9911	6·895	·9402	6·574	·8964	6·294	·8582	6·047	·8245	5·828	·7945
6											7·990	1·568	7·617	1·499	7·294	1·432	7·007	1·375	6·752	1·325
7															8·248	2·204	7·924	2·117	7·636	2·010

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	15		16		17		18		19		20		21		22		23		24	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	2·610	·0569	2·527	·0551	2·452	·0534	2·383	·0519	2·318	·0506	2·260	·0493	2·205	·0481	2·154	·0470	2·107	·0460	2·063	·0450
3	3·687	·1810	3·570	·1752	3·464	·1700	3·366	·1652	3·276	·1608	3·193	·1567	3·116	·1529	3·044	·1494	2·977	·1461	2·914	·1430
4	4·688	·4091	4·539	·3961	4·403	·3843	4·279	·3734	4·165	·3634	4·059	·3542	3·961	·3457	3·870	·3377	3·785	·3303	3·705	·3233
5	5·629	·7675	5·450	·7432	5·287	·7209	5·150	·7022	5·001	·6819	4·874	·6646	4·757	·6486	4·648	·6337	4·545	·6197	4·449	·6066
6	6·523	1·280	6·316	1·240	6·127	1·203	5·954	1·169	5·795	1·137	5·648	1·108	5·512	1·082	5·385	1·057	5·267	1·034	5·156	1·012
7	7·377	1·971	7·142	1·908	6·929	1·851	6·733	1·799	6·553	1·751	6·388	1·707	6·234	1·666	6·090	1·627	5·956	1·591	5·830	1·558
8	8·196	2·861	7·936	2·770	7·699	2·687	7·482	2·611	7·282	2·542	7·097	2·477	6·927	2·418	6·767	2·362	6·619	2·310	6·479	2·261
9					8·442	3·729	8·204	3·624	7·984	3·527	7·782	3·438	7·595	3·355	7·420	3·278	7·257	3·206	7·104	3·138
10									8·663	4·725	8·444	4·605	8·240	4·494	8·051	4·391	7·874	4·295	7·708	4·204
11															8·663	5·717	8·472	5·591	8·294	5·473

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	25		26		27		28		29		30		31		32		33		34	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	2·021	·0440	1·981	·0432	1·944	·0424	1·909	·0416	1·876	·0409	1·844	·0402	1·814	·0396	1·785	·0389	1·758	·0383	1·732	·0377
3	2·855	·1401	2·800	·1374	2·747	·1348	2·698	·1324	2·651	·1301	2·606	·1279	2·564	·1258	2·523	·1238	2·485	·1219	2·448	·1201
4	3·630	·3168	3·560	·3106	3·493	·3048	3·430	·2993	3·370	·2941	3·313	·2891	3·259	·2844	3·208	·2799	3·159	·2757	3·112	·2716
5	4·359	·5944	4·274	·5828	4·194	·5719	4·118	·5616	4·047	·5518	3·979	·5425	3·914	·5337	3·852	·5252	3·793	·5172	3·737	·5095
6	5·052	·9919	4·954	·9726	4·862	·9544	4·774	·9371	4·690	·9208	4·611	·9054	4·535	·8907	4·463	·8766	4·395	·8631	4·330	·8503
[illegible]	[illegible]	[illegible]	5·601	1·497	5·497	1·469	5·398	1·442	5·303	1·417	5·214	1·393	5·129	1·371	5·048	1·349	4·971	1·328	4·898	1·309
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5·794	2·022	5·699	1·989	5·609	1·958	5·524	1·928	5·442	1·899

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

SINE OF INCLINATION. (1 over:—)

Diameter in Inches.	25 V.	25 Q.	26 V.	26 Q.	27 V.	27 Q.	28 V.	28 Q.	29 V.	29 Q.	30 V.	30 Q.	31 V.	31 Q.	32 V.	32 Q.	33 V.	33 Q.	34 V.	34 Q.
9	6·960	3·075	6·825	3·015	6·697	2·958	6·576	2·905	6·462	2·854	6·353	2·806	6·249	2·761	6·151	2·717	6·057	2·675	5·967	2·636
10	7·552	4·119	7·405	4·039	7·266	3·963	7·135	3·891	7·011	3·823	6·893	3·759	6·781	3·698	6·674	3·640	6·572	3·584	6·474	3·531
11	8·258	5·450	7·968	5·258	7·819	5·160	7·678	5·067	7·544	4·979	7·417	4·895	7·296	4·815	7·181	4·739	7·072	4·667	6·967	4·598
12	8·704	6·836	8·515	6·688	8·356	6·562	8·205	6·444	8·062	6·332	7·926	6·225	7·797	6·124	7·674	6·027	7·557	5·935	7·445	5·847
13					8·878	8·183	8·718	8·036	8·567	7·896	8·423	7·763	8·285	7·637	8·154	7·516	8·029	7·401	7·910	7·291
14											8·905	9·498	8·760	9·343	8·622	9·196	8·490	9·055	8·364	8·921
15																	8·940	1·097	8·808	10·81

SINE OF INCLINATION. (1 over:—)

Diameter in Inches.	35 V.	35 Q.	36 V.	36 Q.	37 V.	37 Q.	38 V.	38 Q.	39 V.	39 Q.	40 V.	40 Q.	41 V.	41 Q.	42 V.	42 Q.	43 V.	43 Q.	44 V.	44 Q.
2	1·707	·0372	1·683	·0367	1·660	·0362	1·637	·0357	1·617	0·352	1·596	·0348	1·577	·3441	1·558	·0340	1·540	·0336	1·522	·0332
3	2·412	·1184	2·378	·1167	2·346	·1151	2·315	·1136	2·285	·1121	2·256	·1107	2·228	·1094	2·202	·1081	2·176	·1068	2·151	·1056
4	3·067	·2677	3·024	·2639	2·983	·2603	2·943	·2568	2·905	·2535	2·869	·2503	2·833	·2472	2·799	·2443	2·767	·2414	2·735	·2386
5	3·684	·5022	3·631	·4951	3·582	·4884	3·534	·4819	3·488	·4757	3·445	·4697	3·402	·4639	3·361	·4583	3·322	·4530	3·284	·4478
6	4·268	·8381	4·208	·8263	4·151	·8150	4·096	·8042	4·043	·7938	3·992	·7838	3·943	·7742	3·895	·7649	3·850	·7559	3·806	·7473
7	4·827	1·290	4·759	1·272	4·694	1·255	4·632	1·238	4·572	1·222	4·514	1·206	4·459	1·191	4·406	1·177	4·354	1·163	4·304	1·150
8	5·363	1·872	5·288	1·846	5·216	1·821	5·147	1·796	5·080	1·773	5·016	1·751	4·955	1·729	4·895	1·708	4·838	1·688	4·782	1·669
9	5·881	2·598	5·798	2·561	5·719	2·526	5·644	2·493	5·570	2·461	5·500	2·430	5·433	2·400	5·368	2·371	5·305	2·343	5·244	2·316
10	6·381	3·480	6·292	3·431	6·207	3·384	6·124	3·339	6·044	3·296	5·968	3·255	5·895	3·215	5·825	3·176	5·756	3·139	5·690	3·103
11	6·866	4·532	6·770	4·468	6·678	4·407	6·589	4·348	6·504	4·292	6·422	4·238	6·343	4·186	6·267	4·136	6·194	4·088	6·123	4·041
12	7·338	5·763	7·235	5·682	7·136	5·605	7·041	5·531	6·950	5·459	6·863	5·390	6·779	5·324	6·698	5·260	6·619	5·198	6·543	5·139
13	7·796	7·186	7·687	7·086	7·582	6·989	7·482	6·896	7·385	6·807	7·292	6·722	7·203	6·639	7·117	6·565	7·033	6·482	6·952	6·408
14	8·244	8·793	8·129	8·670	8·018	8·551	7·911	8·438	7·809	8·329	7·711	8·224	7·617	8·123	7·525	8·025	7·436	7·931	7·351	7·840
15	8·681	10·65	8·559	10·50	8·443	10·36	8·331	10·22	8·223	10·09	8·119	9·964	8·019	9·841	7·923	9·723	7·830	9·609	7·741	9·499
16			8·980	12·53	8·858	12·36	8·741	12·20	8·628	12·04	8·519	11·89	8·414	11·75	8·313	11·61	8·216	11·47	8·122	11·34
17									9·044	14·25	8·931	14·07	8·821	13·90	8·715	13·73	8·613	13·57	8·515	13·42
18															9·069	16·02	8·963	15·83	8·860	15·65

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	45		46		47		48		49		50		51		52		53		54	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·505	·0328	1·488	·0324	1·472	·0321	1·457	·0318	1·442	·0314	1·427	·0311	1·412	·0308	1·397	·0305	1·386	·0302	1·373	·0299
3	2·127	·1044	2·104	·1032	2·081	·1021	2·059	·1010	2·038	·1000	2·017	·0990	1·997	·0980	1·978	·0971	1·959	·0961	1·941	·0952
4	2·704	·2360	2·674	·2334	2·646	·2309	2·618	·2285	2·591	·2261	2·565	·2238	2·540	·2216	2·515	·2195	2·491	·2174	2·468	·2154
5	3·247	·4428	3·212	·4379	3·177	·4332	3·144	·4287	3·112	·4243	3·081	·4200	3·050	·4158	3·020	·4118	2·991	·4079	2·963	·4041
6	3·763	·7389	3·722	·7308	3·682	·7230	3·643	·7154	3·606	·7080	3·569	·7009	3·534	·6940	3·500	·6873	3·467	·6807	3·434	·6744
7	4·256	1·137	4·209	1·125	4·164	1·113	4·120	1·101	4·078	1·089	4·037	1·078	3·997	1·068	3·958	1·057	3·921	1·047	3·884	1·037
8	4·729	1·650	4·677	1·632	4·627	1·615	4·578	1·598	4·531	1·581	4·486	1·565	4·441	1·550	4·398	1·535	4·357	1·520	4·316	1·506
9	5·185	2·290	5·129	2·265	5·073	2·241	5·020	2·218	4·969	2·195	4·919	2·173	4·870	2·151	4·823	2·130	4·777	2·110	4·733	2·090
10	5·626	3·068	5·564	3·034	5·505	3·002	5·447	2·970	5·391	2·940	5·337	2·911	5·284	2·882	5·233	2·854	5·183	2·827	5·135	2·801
11	6·054	3·995	5·988	3·951	5·924	3·909	5·862	3·868	5·802	3·828	5·743	3·790	5·686	3·753	5·631	3·716	5·578	3·681	5·526	3·647
12	6·470	5·082	6·399	5·027	6·330	4·973	6·264	4·921	6·200	4·869	6·138	4·820	6·077	4·772	6·018	4·726	5·961	4·681	5·905	4·638
13	6·874	6·336	6·799	6·267	6·726	6·200	6·656	6·135	6·588	6·072	6·521	6·011	6·457	5·952	6·394	5·894	6·333	5·838	6·274	5·783
14	7·269	7·753	7·190	7·668	7·112	7·586	7·038	7·506	6·966	7·429	6·895	7·354	6·827	7·282	6·761	7·211	6·697	7·143	6·635	7·076
15	7·654	9·393	7·570	9·290	7·489	9·191	7·411	9·095	7·335	9·001	7·261	8·910	7·189	8·822	7·119	8·737	7·052	8·654	6·986	8·573
16	8·031	11·21	7·943	11·09	7·858	10·97	7·776	10·85	7·697	10·74	7·620	10·63	7·544	10·53	7·470	10·43	7·399	10·33	7·330	10·23
17	8·420	13·27	8·328	13·12	8·239	12·98	8·152	12·84	8·069	12·71	7·987	12·58	7·908	12·46	7·831	12·37	7·757	12·22	7·685	12·11
18	8·761	15·48	8·665	15·31	8·572	15·14	8·482	14·98	8·395	14·83	8·311	14·68	8·229	14·54	8·150	14·40	8·072	14·26	7·997	14·13
19	9·137	17·99	9·037	17·79	8·940	17·60	8·846	17·41	8·755	17·23	8·667	17·06	8·582	16·89	8·499	16·73	8·418	16·57	8·339	16·42
20							9·162	19·99	9·068	19·78	8·977	19·58	8·889	19·39	8·803	19·20	8·719	19·02	8·638	18·84
21													9·209	22·15	9·120	21·93	9·034	21·72	8·950	21·52

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	55		56		57		58		59		60		61		62		63		64	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·361	·0296	1·348	·0294	1·336	·0291	1·325	·0289	1·313	·0286	1·302	·0284	1·291	·0282	1·281	·0279	1·271	·0277	1·261	·0275
3	1·923	·0944	1·906	·0935	1·889	·0927	1·873	·0919	1·857	·0911	1·841	·0903	1·826	·0896	1·811	·0889	1·797	·0882	1·782	·0875
4	2·445	·2134	2·423	·2115	2·402	·2096	2·381	·2078	2·361	·2060	2·341	·2043	2·322	·2026	2·303	·2009	2·284	·1993	2·266	·1977
5	2·936	·4004	2·910	·3968	2·884	·3933	2·859	·3899	2·835	·3865	2·811	·3833	2·788	·3801	2·765	·3770	2·743	·3740	2·721	·3711
6	3·403	·6682	3·372	·6622	3·342	·6563	3·313	·6506	3·285	·6451	3·258	·6397	3·231	·6344	3·204	·6292	3·179	·6242	3·154	·6193
7	3·848	1·028	3·814	1·019	3·780	1.010	3·747	1·001	3·715	·9930	3·684	·9847	3·654	·9765	3·624	·9686	3·595	·9609	3·567	·9533
8	4·276	1·492	4·238	1·479	4·200	1·466	4·164	1·453	4·128	1·441	4·094	1·429	4·060	1·417	4·027	1·405	3·995	1·394	3·963	1·383
9	4·689	2·071	4·647	2·053	4·606	2·035	4·566	2·017	4·527	2·000	4·489	1·983	4·452	1·967	4·416	1·951	4·381	1·935	4·346	1·920

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	55		56		57		58		59		60		61		62		63		64	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
10	5·088	2·775	5·042	2·750	4·998	2·726	4·954	2·702	4·912	2·679	4·871	2·656	4·831	2·634	4·792	2·613	4·753	2·592	4·716	2·572
11	5·475	3·613	5·426	3·581	5·378	3·549	5·331	3·518	5·286	3·488	5·242	3·459	5·198	3·430	5·156	3·402	5·115	3·375	5·075	3·349
12	5·851	4·596	5·798	4·555	5·747	4·515	5·697	4·475	5·649	4·436	5·601	4·399	5·555	4·363	5·510	4·327	5·466	4·293	5·423	4·259
13	6·217	5·730	6·161	5·679	6·107	5·629	6·054	5·580	6·002	5·532	5·952	5·486	5·903	5·441	5·855	5·397	5·808	5·354	5·762	5·311
14	6·574	7·011	6·515	6·948	6·458	6·887	6·403	6·827	6·348	6·771	6·293	6·712	6·241	6·657	6·191	6·603	6·141	6·550	6·093	6·499
15	6·922	8·495	6·860	8·419	6·799	8·344	6·740	8·272	6·683	8·201	6·627	8·132	6·572	8·065	6·519	8·000	6·467	7·936	6·416	7·874
16	7·263	10·14	7·198	10·05	7·134	9·961	7·072	9·875	7·012	9·791	6·953	9·708	6·896	9·628	6·840	9·550	6·785	9·474	6·732	9·400
17	7·615	12·00	7·546	11·89	7·479	11·78	7·414	11·68	7·351	11·58	7·289	11·49	7·229	11·39	7·171	11·30	7·113	11·21	7·057	11·12
18	7·924	14·00	7·852	13·87	7·784	13·75	7·717	13·63	7·650	13·51	7·586	13·40	7·523	13.29	7·462	13·18	7·402	13·08	7·344	12·97
19	8·263	16·27	8·189	16·12	8·116	15·98	8·046	15·84	7·977	15·70	7·911	15·57	7·845	15·44	7·782	15·32	7·720	15·20	7·659	15·08
20	8·559	18·67	8·482	18·50	8·407	18·34	8·344	18·18	8·263	18·02	8·194	17·87	8·126	17·72	8·060	17·58	7·996	17·44	7·933	17·30
21	8·868	21·33	8·788	21·14	8·710	20·95	8·635	20·77	8·562	20·59	8·490	20·42	8·420	20·25	8·352	20·08	8·285	19·92	8·220	19·77
22	9·171	24·21	9·089	23·99	9·009	23·78	8·931	23·57	8·855	23·37	8·781	23·18	8·708	22·99	8·637	22·80	8·568	22·62	8·501	22·44
23							9·222	26·60	9·143	26·38	9·067	26·16	8·992	25·94	8·919	25·73	8·848	25·52	8·778	25·32
24													9·271	29·12	9·196	28·89	9·122	28·66	9·052	28·43

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	65		66		67		68		69		70		71		72		73		74	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·251	·0273	1·242	·0270	1·232	·0268	1·223	·0267	1·214	·0265	1·206	·0263	1·197	·0261	1·189	·0268	1·180	·0257	1·172	·0255
3	1·769	·0868	1·755	·0861	1·742	·0855	1·729	·0849	1·716	·0842	1·704	·0836	1·692	·0830	1·680	·0824	1·668	·0819	1·657	·0813
4	2·249	·1962	2·231	·1947	2·215	·1933	2·198	·1919	2·182	·1905	2·167	·1891	2·151	·1877	2·136	·1864	2·121	·1851	2·107	·1838
5	2·700	·3682	2·680	·3654	2·660	·3626	2·640	·3599	2·621	·3573	2·602	·3548	2·583	·3522	2·556	·3496	2·547	·3474	2·530	·3450
6	3·129	·6145	3·105	·6098	3·082	·6052	3·060	·6007	3·037	·5963	3·015	·5920	2·994	·5878	2·973	·5837	2·952	·5797	2·932	·5758
7	3·539	·9459	3·512	·9387	3·486	·9316	3·460	·9247	3·435	·9180	3·410	·9114	3·386	·9049	3·362	·8986	3·339	·8924	3·316	·8864
8	3·933	1·372	3·903	1·362	3·873	1·352	3·845	1·342	3·817	1·332	3·789	1·322	3·762	1·313	3·736	1·304	3·710	1·295	3·685	1·286
9	4·312	1·905	4·279	1·890	4·247	1·876	4·217	1·863	4·185	1·849	4·155	1·835	4·126	1·822	4·097	1·810	4·069	1·797	4·041	1·789
10	4·679	2·552	4·644	2·532	4·609	2·513	4·574	2·495	4·541	2·477	4·509	2·459	4·477	2·441	4·446	2·424	4·415	2·408	4·385	2·391
11	5·035	3·323	4·997	3·298	4·959	3·273	4·923	3·249	4·887	3·225	4·852	3·202	4·817	3·179	4·784	3·157	4·751	3·136	4·718	3·116
12	5·381	4·226	5·340	4·194	5·300	4·162	5·261	4·132	5·223	4·102	5·186	4·072	5·149	4·043	5·112	4·015	5·076	3·987	5·042	3·960
13	5·717	5·270	5·674	5·230	5·631	5·191	5·590	5·153	5·549	5·115	5·509	5·077	5·470	5·042	5·432	5·007	5·394	4·972	5·358	4·939
14	6·046	6·448	6·000	6·399	5·955	6·351	5·911	6·305	5·868	6·258	5·825	6·213	5·784	6·169	5·744	6·126	5·704	6·084	5·664	6·041

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	65		66		67		68		69		70		71		72		73		74	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
15	6·366	7·813	6·318	7·753	6·271	7·695	6·225	7·639	6·179	7·582	6·134	7·528	6·091	7·474	6·048	7·422	6·007	7·371	5·966	7·321
16	6·680	9·327	6·629	9·256	6·594	9·186	6·532	9·120	6·484	9·052	6·437	8·987	6·391	8·923	6·346	8·861	6.302	8·800	6·259	8·740
17	7·003	11·03	6·949	10·95	6·897	10·87	6·847	10·79	6·797	10·71	6·748	10·63	6·700	10·56	6·653	10·48	6·607	10·41	6·562	10·34
18	7·288	12·87	7·232	12·77	7·177	12·68	7·124	12·59	7·072	12·50	7·022	12·41	6·972	12·32	6·923	12·23	6·876	12·14	6·829	12·06
19	7·600	14·96	7·542	14·84	7·485	14·73	7·430	14·62	7·376	14·51	7·323	14·41	7·271	14·31	7·220	14·21	7·170	14·11	7·121	14·01
20	7·872	17·17	7·812	17·04	7·754	16·91	7·697	16·79	7·640	16·66	7·585	16·54	7·531	16·42	7·478	16·31	7·427	16·20	7·376	16·09
21	8·156	19·61	8·094	19·46	8·033	19·32	7·974	19·18	7·916	19·04	7·859	18·90	7·803	18·76	7·748	18·63	7·695	18·51	7·643	18·38
22	8·435	22·26	8·371	22·09	8·308	21·92	8·247	21·76	8·187	21·61	8·128	21·46	8·070	21·30	8·014	21·15	7·959	21·01	7·905	20·87
23	8·710	25·13	8·644	24·94	8·579	24·75	8·516	24·57	8·454	24·39	8·393	24·21	8·333	24·04	8·275	23·87	8·218	23·71	8·162	23·55
24	8·982	28·21	8·912	28·00	8·845	27·79	8·780	27·58	8·717	27·38	8·654	27·18	8·592	26·99	8·531	26·80	8·472	26·61	8·415	26·43
26							9·299	34·28	9·230	34·03	9·163	33·78	9·098	33·54	9·035	33·31	8·973	33·08	8·912	32·86
27																	9·217	36·64	9·154	36·40

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	75		76		77		78		79		80		81		82		83		84	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·164	·0254	1·156	·0252	1·149	·0250	1·142	·0249	1·134	·0247	1·127	·0246	1·120	·0244	1·113	·0243	1·107	·0241	1·100	·0240
3	1·656	·0808	1·635	·0802	1·624	·0797	1·614	·0792	1·604	·0787	1·593	·0782	1·583	·0777	1·574	·0772	1·564	·0768	1·555	·0763
4	2·093	·1826	2·079	·1814	2·065	·1802	2·052	·1790	2·039	·1779	2·026	·1768	2·013	·1757	2·001	·1746	1·988	·1735	1·977	·1725
5	2·513	·3427	2·496	·3404	2·480	·3382	2·464	·3360	2·448	·3339	2·433	·3318	2·418	·3297	2·403	·3276	2·388	·3256	2·374	·3237
6	2·912	·5719	2·893	·5680	2·874	·5644	2·856	·5608	2·837	·5572	2·820	·5537	2·802	·5502	2·785	·5468	2·768	·5435	2·751	·5403
7	3·294	·8804	3·272	·8745	3·251	·8688	3·230	·8632	3·209	·8577	3·189	·8523	3·169	·8470	3·150	·8418	3·130	·8367	3·112	·8317
8	3·660	1·277	3·636	1·269	3·613	1·261	3·589	1·253	3·566	1·245	3·544	1·237	3·522	1·229	3·500	1·221	3·479	1·214	3·458	1·207
9	4·014	1·773	3·987	1·761	3·961	1·750	3·936	1·738	3·910	1·727	3·886	1·716	3·862	1·706	3·838	1·695	3·814	1·685	3·792	1·675
10	4·356	2·375	4·327	2·359	4·298	2·344	4·270	2·329	4·243	2·314	4·216	2·299	4·190	2·285	4·165	2·271	4·140	2·257	4·115	2·244
11	4·687	3·097	4·657	3·078	4·636	3·059	4·595	3·032	4·566	3·013	4·537	3·001	4·509	2·976	4·481	2·957	4·464	2·946	4·428	2·922
12	5·008	3·933	4·975	3·907	4·943	3·882	4·911	3·857	4·880	3·832	4·849	3·808	4·819	3·785	4·789	3·761	4·760	3·738	4·731	3·716
13	5·322	4·905	5·287	4·873	5·252	4·841	5·218	4·810	5·185	4·779	5·152	4·749	5·120	4·720	5·089	4·691	5·058	4·662	5·028	4·634
14	5·627	6·001	5·590	5·962	5·554	5·923	5·518	5·885	5·483	5·848	5·448	5·811	5·414	5·775	5·381	5·739	5·348	5·709	5·316	5·671
15	5·926	7·272	5·887	7·224	5·848	7·177	5·802	7·120	5·773	7·085	5·737	7·040	5·701	6·997	5·665	6·952	5·631	6·911	5·598	6·870
[illegible]	[illegible]	[illegible]	6·177	8·624	6·136	8·568	6·096	8·513	6·058	8·459	6·020	8·406	5·982	8·353	5·945	8·302	5·909	8·251	5·874	8·202

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	75		76		77		78		79		80		81		82		83		84	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
17	6·518	10·27	6·475	10·20	6·433	10·14	6·392	10·07	6·351	10·01	6·311	9·947	6·272	9·886	6·233	9·825	6·195	9·765	6·158	9·707
18	6·783	11·98	6·738	11·90	6·694	11·83	6·651	11·75	6·624	11·67	6·582	11·60	6·526	11·53	6·486	11·46	6·447	11·39	6·407	11·32
19	7·074	13·92	7·027	13·83	6·981	13·74	6·936	13·65	6·892	13·57	6·849	13·48	6·806	13·40	6·764	13·31	6·722	13·23	6·683	13·15
20	7·327	15·98	7·278	15·88	7·231	15·78	7·184	15·67	7·139	15·57	7·094	15·47	7·050	15·37	7·006	15·28	6·964	15·19	6·922	15·10
21	7·592	18·26	7·542	18·14	7·492	18·02	7·444	17·90	7·397	17·79	7·350	17·68	7·304	17·57	7·259	17·46	7·215	17·35	7·172	17·25
22	7·852	20·73	7·800	20·59	7·749	20·45	7·699	20·32	7·650	20·19	7·602	20·06	7·555	19·94	7·508	19·82	7·462	19·70	7·417	19·58
23	8·108	23·39	8·054	23·23	8·001	23·08	7·950	22·93	7·899	22·79	7·850	22·65	7·801	22·51	7·753	22·37	7·706	22·23	7·661	22·09
24	8·359	26·26	8·304	26·09	8·250	25·92	8·197	25·75	8·145	25·58	8·094	25·42	8·044	25·26	7·995	25·10	7·946	24·95	7·898	24·80
26	8·852	32·64	8·793	32·42	8·736	32·21	8·680	32·00	8·624	31·80	8·570	31·60	8·517	31·40	8·465	31·21	8·413	31·02	8·363	30·83
27	9·093	36·15	9·034	35·91	8·974	35·68	8·916	35·45	8·858	35·22	8·803	35·00	8·749	34·78	8·695	34·57	8·643	34·36	8·591	34·16
30																	9·311	45·70	9·255	35·43

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	85		86		87		88		89		90		91		92		93		94	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·093	·0239	1·087	·0237	1·081	·0235	1·074	·0234	1·068	·0232	1·062	·0231	1·056	·0230	1·051	·0229	1·045	·0228	1·039	·0226
3	1·546	·0758	1·536	·0754	1·528	·0750	1·519	·0745	1·510	·0741	1·502	·0737	1·493	·0733	1·485	·0729	1·477	·0725	1·469	·0721
4	1·965	·1715	1·954	·1705	1·942	·1695	1·939	·1685	1·920	·1675	1·910	·1666	1·899	·1657	1·889	·1648	1·878	·1639	1·868	·1630
5	2·360	·3218	2·346	·3199	2·333	·3181	2·311	·3162	2·306	·3144	2·293	·3127	2·280	·3110	2·268	·3093	2·256	·3076	2·244	·3059
6	2·735	·5371	2·719	·5339	2·703	·5308	2·688	·5278	2·673	·5248	2·658	·5218	2·643	·5189	2·628	·5161	2·614	·5133	2·600	·5106
7	3·093	·8268	3·075	·8219	3·057	·8172	3·040	·8125	3·023	·8079	3·006	·8034	2·989	·7989	2·973	·7946	2·957	·7903	2·941	·7860
8	3·438	1·200	3·417	1·193	3·398	1·186	3·378	1·179	3·359	1·172	3·340	1·166	3·322	1·159	3·304	1·153	3·286	1·147	3·268	1·140
9	3·769	1·665	3·747	1·655	3·726	1·646	3·704	1·636	3·683	1·627	3·663	1·618	3·642	1·609	3·623	1·600	3·603	1·591	3·584	1·583
10	4·090	2·231	4·066	2·218	4·043	2·205	4·020	2·192	3·997	2·181	3·975	2·171	3·953	2·155	3·931	2·144	3·910	2·132	3·889	2·120
11	4·401	2·838	4·386	2·895	4·360	2·877	4·336	2·861	4·311	2·845	4·287	2·829	4·263	2·813	4·241	2·799	4·217	2·783	4·194	2·768
12	4·705	3·695	4·676	3·673	4·648	3·651	4·622	3·630	4·596	3·610	4·570	3·590	4·544	3·570	4·520	3·550	4·496	3·531	4·472	3·512
13	4·998	4·607	4·969	4·580	4·940	4·554	4·912	4·527	4·884	4·502	4·857	4·477	4·830	4·452	4·803	4·428	4·777	4·404	4·752	4·380
14	5·285	5·637	5·254	5·604	5·224	5·572	5·194	5·540	5·165	5·508	5·136	5·477	5·107	5·447	5·079	5·417	5·052	5·388	5·025	5·359
15	5·565	6·829	5·533	6·789	5·501	6·750	5·469	6·712	5·438	6·674	5·407	6·637	5·377	6·600	5·349	6·564	5·320	6·528	5·291	6·493
16	5·839	8·153	5·805	8·106	5·772	8·059	5·739	8·013	5·706	7·967	5·674	7·923	5·643	7·879	5·612	7 836	5·581	7·792	5·552	7·752
17	6·122	9·650	6·086	9·593	6·051	9·538	6·016	9·483	5·982	9·430	5·949	9·377	5·916	9·325	5·883	9·274	5·851	9·224	5·820	9·175
18	6·370	11·25	6·333	11·19	6·297	11·12	6·261	11·06	6·225	11·00	6·190	10·94	6·156	10·88	6·123	10·82	6·090	10·76	6·057	10·70

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	85		86		87		88		89		90		91		92		93		94	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
19	6·644	13·08	6·605	13·00	6·567	12·93	6·529	12·85	6·492	12·78	6·455	12·71	6·420	12·64	6·385	12·57	6·351	12·50	6·317	12·43
20	6·881	15·01	6·841	14·92	6·802	14·84	6·763	14·75	6·725	14·67	6·687	14·59	6·650	14·50	6·613	14·42	6·577	14·35	6·542	14·27
21	7·130	17·15	7·088	17·05	7·047	16·95	7·007	16·85	6·968	16·75	6·928	16·66	6·890	16·57	6·853	16·48	6·816	16·39	6·779	16·30
22	7·374	19·46	7·331	19·35	7·289	19·24	7·247	19·13	7·206	19·02	7·166	18·91	7·126	18·81	7·087	18·71	7·049	18·60	7·011	18·51
23	7·615	21·96	7·570	21·84	7·526	21·71	7·483	21·59	7·441	21·47	7·400	21·35	7·359	21·23	7·318	21·11	7·279	21·00	7·240	20·89
24	7·851	24·66	7·805	24·52	7·760	24·38	7·716	24·24	7·672	24·10	7·629	23·96	7·587	23·83	7·546	23·70	7·505	23·57	7·465	23·45
26	8·314	30·65	8·265	30·47	8·217	30·29	8·170	30·12	8·124	29·95	8·079	29·78	8·034	29·62	7·990	29·46	7·947	29·30	7·905	29·14
27	8·540	33·95	8·490	33·75	8·441	33·36	8·393	33·37	8·346	33·18	8·299	32·99	8·253	32·81	8·208	32·63	8·163	32·45	8·120	32·28
30	9·201	45·16	9·147	44·90	9·094	44·64	9·042	44·38	8·991	44·13	8·941	43·88	8·892	43·64	8·843	43·40	8·795	43·17	8·748	42·94
33																			9·353	55·55

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	95		96		97		98		99		100		105		110		115		120	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	1·034	·0225	1·028	·0224	1·023	·0223	1·018	·0222	1·013	·0221	1·008	·0219	·9835	·0214	·9607	·0209	·9394	·0204	·9195	·0200
3	1·461	·0717	1·454	·0713	1·446	·0710	1·439	·0706	1·431	·0702	1·424	·0699	1·390	·0682	1·358	·0666	1·327	·0651	1·299	·0638
4	1·858	·1622	1·849	·1613	1·839	·1605	1·830	·1597	1·820	·1588	1·811	·1580	1·767	·1542	1·726	·1506	1·688	·1473	1·652	·1442
5	2·232	·3043	2·220	·3027	2·208	·3011	2·198	·2996	2·186	·2981	2·175	·2966	2·122	·2894	2·073	·2827	2·032	·2764	1·984	·2706
6	2·586	·5079	2·573	·5052	2·560	·5026	2·546	·5000	2·533	·4975	2·521	·4950	2·460	·4830	2·403	·4718	2·350	·4614	2·300	·4516
7	2·925	·7819	2·910	·7778	2·895	·7737	2·880	·7697	2·865	·7658	2·851	·7620	2·782	·7435	2·718	·7263	2·658	·7103	2·601	·6953
8	3·251	1·134	3·234	1·128	3·217	1·123	3·200	1·117	3·184	1·111	3·168	1·106	3·091	1·079	3·020	1·054	2·953	1·031	2·891	1·009
9	3·565	1·575	3·546	1·566	3·528	1·558	3·509	1·550	3·492	1·542	3·474	1·535	3·390	1·497	3·312	1·463	3·238	1·430	3·170	1·400
10	3·868	2·109	3·848	2·098	3·828	2·087	3·808	2·077	3·789	2·067	3·770	2·057	3·679	2·008	3·594	1·962	3·514	1·913	3·441	1·873
11	4·173	2·754	4·150	2·739	4·119	2·718	4·109	2·712	4·086	2·697	4·066	2·683	3·959	2·612	3·867	2·552	3·782	2·496	3·702	2·443
12	4·448	3·494	4·425	3·475	4·402	3·457	4·379	3·440	4·358	3·423	4·335	3·405	4·230	3·322	4·133	3·246	4·042	3·174	3·956	3·107
13	4·727	4·357	4·702	4·334	4·678	4·312	4·654	4·289	4·630	4·267	4·607	4·246	4·495	4·143	4·391	4·048	4·294	3·959	4·204	3·876
14	4·998	5·331	4·971	5·303	4·946	5·275	4·921	5·248	4·896	5·222	4·871	5·195	4·753	5·070	4·644	4·953	4·542	4·844	4·445	4·741
15	5·263	6·459	5·236	6·425	5·209	6·392	5·182	6·359	5·156	6·327	5·131	6·296	5·007	6·144	4·890	6·002	4·782	5·869	4·681	5·744
16	5·523	7·711	5·494	7·670	5·465	7·631	5·437	7·592	5·409	7·553	5·382	7·515	5·252	7·333	5·131	7·164	5·018	7·006	4·912	6·858
17	5·789	9·126	5·759	9·078	5·729	9·032	5·700	8·985	5·671	8·939	5·643	8·894	5·506	8·679	5·379	8·479	5·260	8·292	5·149	8·117
18	6·025	10·64	5·993	10·59	5·962	10·53	5·932	10·48	5·902	10·43	5·872	10·38	5·730	10·13	5·598	9·892	5·474	9·674	5·358	9·469
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12·24	6·186	12·18	6·154	12·11	6·122	12·05	5·975	11·76	5·838	11·49	5·709	11·24	5·588	11·00

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	95		96		97		98		99		100		105		110		115		120	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
20	6·508	14·19	6·474	14·12	6·440	14·05	6·407	13·98	6·375	13·91	6·343	13·85	6·189	13·52	6·047	13·20	5·913	12·90	5·788	12·62
21	6·743	16·21	6·708	16·13	6·673	16·05	6·639	15·97	6·605	15·88	6·572	15·80	6·413	15·42	6·265	15·07	6·127	14·74	5·998	14·43
22	6·974	18·41	6·938	18·31	6·902	18·22	6·866	18·12	6·831	18·03	6·797	17·94	6·633	17·50	6·480	17·10	6·337	16·72	6·203	16·37
23	7·201	20·78	7·164	20·67	7·127	20·56	7·090	20·45	7·054	20·35	7·019	20·25	6·849	19·76	6·691	19·30	6·544	18·88	6·407	18·48
24	7·425	23·33	7·386	23·21	7·348	23·09	7·310	22·97	7·273	22·85	7·237	22·73	7·062	22·18	6·899	21·67	6·747	21·20	6·605	20·75
26	7·863	28·99	7·822	28·84	7·781	28·69	7·740	28·54	7·702	28·39	7·663	28·25	7·478	27·57	7·306	26·94	7·145	26·35	6·994	25·79
27	8·077	32·11	8·035	31·94	7·993	31·78	7·952	31·62	7·912	31·45	7·870	31·29	7·682	30·54	7·505	29·84	7·339	29·18	7·184	28·56
30	8·702	42·71	8·656	42·49	8·611	42·27	8·567	42·05	8·524	41·84	8·481	41·63	8·276	40·62	8·085	39·68	7·907	38·81	7·740	37·99
33	9·303	55·26	9·255	54·97	9·207	54·68	9·160	54·40	9·113	54·12	9·067	53·85	8·848	52·55	8·644	51·34	8·454	50·21	8·276	49·15
36													9·401	66·45	9·184	64·92	8·982	63·49	8·792	62·15
39																			9·293	77·09

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	125		130		135		140		145		150		155		160		165		170	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	·9008	·0196	·8831	·0192	·8665	·0189	·8507	·0185	·8358	·0182	·8217	·0179	·8082	·0176	·7953	·0174	·7830	·0171	·7713	·0168
3	1·273	·0625	1·248	·0612	1·224	·0601	1·202	·0590	1·182	·0580	1·162	·0570	1·142	·0561	1·124	·0552	1·107	·0543	1·091	·0535
4	1·619	·1412	1·587	·1385	1·557	·1359	1·529	·1334	1·501	·1311	1·476	·1289	1·453	·1268	1·430	·1248	1·408	·1228	1·387	·1210
5	1·944	·2651	1·906	·2599	1·870	·2550	1·836	·2504	1·804	·2460	1·774	·2419	1·745	·2379	1·717	·2341	1·691	·2305	1·665	·2271
6	2·253	·4424	2·209	·4338	2·167	·4257	2·128	·4179	2·091	·4106	2·056	·4036	2·021	·3969	1·990	·3908	1·960	·3847	1·930	·3790
7	2·548	·6811	2·499	·6678	2·452	·6552	2·407	·6434	2·365	·6321	2·325	·6215	2·287	·6112	2·251	·6016	2·216	·5923	2·183	·5835
8	2·832	·9886	2·777	·9693	2·724	·9511	2·675	·9339	2·629	·9176	2·584	·9021	2·542	·8873	2·502	·8732	2·463	·8598	2·426	·8469
9	3·106	1·372	3·045	1·345	2·988	1·320	2·933	1·296	2·883	1·274	2·834	1·252	2·787	1·234	2·743	1·212	2·701	1·193	2·661	1·175
10	3·370	1·838	3·305	1·802	3·242	1·768	3·183	1·736	3·128	1·706	3·076	1·678	3·025	1·650	2·977	1·624	2·931	1·599	2·888	1·575
11	3·626	2·393	3·556	2·346	3·489	2·303	3·426	2·261	3·367	2·222	3·309	2·184	3·255	2·148	3·204	2·114	3·154	2·082	3.107	2·051
12	3·876	3·044	3·800	2·984	3·731	2·928	3·661	2·875	3·598	2·826	3·537	2·778	3·479	2·732	3·424	2·689	3·371	2·648	3·321	2·608
13	4·119	3·797	4·038	3·722	3·962	3·652	3·890	3·586	3·823	3·524	3·758	3·464	3·696	3·407	3·638	3·353	3·582	3·302	3·529	3·253
14	4·355	4·645	4·270	4·554	4·190	4·468	4·114	4·388	4·042	4·311	3·974	4·239	3·909	4·169	3·847	4·103	3·788	4·040	3·732	3·980
15	4·586	5·628	4·496	5·518	4·412	5·414	4·332	5·316	4·257	5·224	4·185	5·136	4·117	5·052	4·052	4·972	3·990	4·896	3·930	4·823
16	4·812	6·719	4·718	6·588	4·630	6·464	4·546	6·347	4·467	6·237	4·391	6·132	4·319	6·031	4·251	5·935	4·186	5·844	4·124	5·757
17	5·045	7·952	4·946	7·797	4·853	7·650	4·766	7·512	4·683	7·381	4·604	7·257	4·528	7·138	4·457	7·025	4·388	6·917	4·323	6·814
18	5·250	9·277	5·148	9·097	5·051	8·926	4·960	8·765	4·873	8·612	4·791	8·467	4·713	8·328	4·638	8·196	4·567	8·070	4·499	7·950

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	125		130		135		140		145		150		155		160		165		170	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
19	5·475	10·78	5·368	10·57	5·267	10·37	5·173	10·18	5·083	10·00	4·997	9·837	4·915	9·677	4·837	9·524	4·763	9·378	4·692	9·238
20	5·671	12·36	5·560	12·12	5·456	11·90	5·357	11·69	5·264	11·48	5·175	11·29	5·091	11·10	5·010	10·93	4·933	10·76	4·860	10·60
21	5·877	14·14	5·762	13·87	5·653	13·59	5·551	13·35	5·455	13·12	5·363	12·90	5·275	12·69	5·191	12·49	5·112	12·30	5·036	12·12
22	6·077	16·04	5·959	15·73	5·847	15·43	5·741	15·16	5·641	14·89	5·546	14·64	5·456	14·40	5·370	14·17	5·287	13·95	5·208	13·75
23	6·276	18·10	6·153	17·74	6·038	17·42	5·929	17·11	5·826	16·81	5·727	16·52	5·634	16·25	5·545	16·00	5·460	15·75	5·379	15·52
24	6·471	20·33	6·345	19·93	6·226	19·55	6·114	19·20	6·007	18·87	5·906	18·55	5·809	18·25	5·717	17·96	5·629	17·69	5·545	17·42
26	6·852	25·26	6·719	24·76	6·593	24·30	6·474	23·87	6·361	23·45	6·254	23·06	6·294	22·68	6·054	22·32	5·961	21·98	5·873	21·65
27	7·039	27·98	6·902	27·44	6·772	26·93	6·650	26·44	6·534	25·98	6·423	25·54	6·319	25·13	6·219	24·73	6·124	24·35	6·033	23·99
30	7·583	37·22	7·436	36·50	7·297	35·82	7·165	35·17	7·040	34·55	6·921	33·97	6·808	33·41	6·701	32·89	6·598	32·39	6·500	31·91
33	8·108	48·16	7·950	47·22	7·801	46·33	7·660	45·50	7·527	44·71	7·400	44·06	7·279	43·23	7·164	42·55	7·054	41·90	6·949	41·28
36	8·614	60·89	8·446	59·70	8·288	58·58	8·139	57·53	7·997	56·52	7·862	55·57	7·733	54·66	7·611	53·80	7·495	52·98	7·383	52·19
39	9·104	75·53	8·927	74·06	8·760	72·67	8·602	71·36	8·453	70·11	8·309	68·93	8·173	67·80	8·044	66·73	7·921	65·71	7·804	64·74
42			9·393	90·37	9·216	88·67	9·050	87·08	8·893	85·56	8·743	84·11	8·600	82·74	8·464	81·44	8·335	80·19	8·211	79·00
45									9·321	103·0	9·164	101·2	9·015	99·56	8·873	97·99	8·737	96·49	8·607	95·06
48													9·419	118·4	9·270	116·5	9·128	114·7	8·992	113·0
51																			9·368	132·9

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	175		180		185		190		195		200		205		210		215		220	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
2	·7601	·0166	·7494	·0164	·7390	·0161	·7291	·0159	·7196	·0157										
3	1·075	·0528	1·059	·0520	1·045	·0513	1·031	·0506	1·017	·0499	1·004	·0493	·9919	·0487	·9799	·0481	·9683	·0475	·9570	·0470
4	1·367	·1193	1·347	·1176	1·328	·1160	1·310	·1144	1·294	·1129	1·277	·1115	1·262	·1101	1·246	·1088	1·231	·1075	1·217	·1062
5	1·641	·2238	1·618	·2206	1·596	·2176	1·574	·2147	1·554	·2119	1·534	·2092	1·515	·2066	1·497	·2041	1·479	·2017	1·462	·1993
6	1·902	·3735	1·876	·3683	1·850	3632	1·825	·3583	1·801	·3536	1·778	·3491	1·756	·3448	1·735	·3407	1·714	·3366	1·695	·3328
7	2·152	·5750	2·122	·5670	2·092	·5591	2·064	·5517	2·037	·5445	2·011	·5376	1·987	·5309	1·963	·5245	1·939	·5183	1·917	·5123
8	2·391	·8346	2·358	·8229	2·325	·8116	2·294	·8008	2·264	·7903	2·235	·7803	2·208	·7706	2·181	·7613	2·155	·7523	2·130	·7436
9	2·622	1·158	2·586	1·142	2·550	1·126	2·516	1·111	2·483	1·097	2·452	1·083	2·421	1·070	2·392	1·057	2·364	1·044	2·336	1·032
10	2·846	1·552	2·806	1·530	2·767	1·509	2·730	1·489	2·695	1·470	2·660	1·451	2·627	1·433	2·596	1·416	2·565	1·399	2·536	1·383
11	3·062	2·021	3·019	1·993	2·978	1·965	2·938	1·939	2·900	1·914	2·863	1·890	2·828	1·867	2·794	1·844	2·761	1·822	2·729	1·801

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	SINE OF INCLINATION. (1 over:—)																			
	175		180		185		190		195		200		205		210		215		220	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
12	3·273	2·570	3·227	2·535	3·182	2·500	3·140	2·467	3·099	2·434	3·060	2·403	3·022	2·374	2·986	2·345	2·950	2·317	2·916	2·291
13	3·478	3·206	3·429	3·161	3·382	3·117	3·337	3·076	3·293	3·036	3·251	2·997	3·211	2·960	3·173	2·924	3·135	2·889	3·099	2·857
14	3·678	3·923	3·626	3·868	3·576	3·814	3·529	3·763	3·483	3·714	3·439	3·667	3·396	3·622	3·355	3·578	3·316	3·536	3·277	3·495
15	3·873	4·753	3·819	4·686	3·767	4·622	3·717	4·561	3·668	4·502	3·621	4·445	3·576	4·389	3·533	4·336	3·492	4·285	3·452	4·235
16	4·064	5·674	4·007	5·594	3·952	5·517	3·899	5·445	3·818	5·373	3·800	5·305	3·753	5·240	3·708	5·177	3·664	5·116	3·622	5·057
17	4·261	6·716	4·201	6·622	4·143	6·530	4·088	6·443	4·035	6·360	3·984	6·279	3·934	6·202	3·887	6·127	3·841	6·054	3·797	5·985
18	4·434	7·836	4·372	7·726	4·312	7·620	4·255	7·518	4·199	7·420	4·146	7·326	4·095	7·236	4·045	7·149	3·995	7·065	3·952	6·983
19	4·624	9·104	4·559	8·977	4·497	8·853	4·437	8·736	4·379	8·622	4·324	8·513	4·271	8·408	4·219	8·307	4·169	8·209	4·121	8·114
20	4·790	10·45	4·723	10·30	4·658	10·16	4·596	10·03	4·536	9·896	4·478	9·770	4·423	9·650	4·370	9·534	4·319	9·422	4·269	9·314
21	4·963	11·94	4·893	11·77	4·826	11·61	4·762	11·45	4·700	11·30	4·641	11·16	4·583	11·02	4·528	10·89	4·475	10·76	4·423	10·64
22	5·133	13·55	5·061	13·36	4·992	13·18	4·925	13·01	4·861	12·84	4·800	12·67	4·741	12·51	4·684	12·36	4·628	12·22	4·575	12·08
23	5·301	15·29	5·227	15·07	5·155	14·87	5·086	14·67	5·020	14·48	4·957	14·30	4·896	14·13	4·836	13·95	4·779	13·79	4·725	13·63
24	5·465	17·17	5·389	16·93	5·315	16·70	5·244	16·48	5·176	16·26	5·111	16·06	5·048	15·86	4·987	15·67	4·928	15·48	4·871	15·30
26	5·788	21·31	5·706	21·04	5·628	20·75	5·553	20·47	5·481	20·21	5·412	19·95	5·345	19·71	5·281	19·47	5·219	19·24	5·159	19·02
27	5·945	23·64	5·862	23·31	5·782	22·99	5·705	22·68	5·631	22·39	5·560	22·11	5·491	21·83	5·425	21·57	5·361	21·32	5·300	21·07
30	6·406	31·44	6·316	31·01	6·230	30·58	6·147	30·17	6·067	29·78	5·990	29·41	5·916	29·04	5·845	28·69	5·777	28·36	5·710	28·03
33	6·849	40·68	6·753	40·11	6·660	39·56	6·572	39·03	6·487	38·53	6·405	38·04	6·326	37·57	6·250	37·12	6·176	36·68	6·105	36·26
36	7·277	51·44	7·175	50·72	7·077	50·02	6·983	49·36	6·892	48·73	6·805	48·11	6·721	47·51	6·640	46·94	6·562	46·39	6·487	45·85
39	7·691	63·80	7·583	62·91	7·480	62·05	7·380	61·22	7·284	60·43	7·192	59·67	7·104	58·93	7·019	58·22	6·936	57·53	6·856	56·87
42	8·093	77·86	7·979	76·77	7·870	75·72	7·765	74·71	7·665	73·74	7·568	72·81	7·475	71·92	7·385	71·06	7·298	70·22	7·214	69·41
45	8·483	93·69	8·364	92·38	8·249	91·12	8·140	89·90	8·035	88·74	7·933	87·62	7·835	86·54	7·741	85·50	7·650	84·49	7·580	83·72
48	8·863	111·4	8·739	109·8	8·619	108·3	8·504	106·9	8·394	105·5	8·288	104·2	8·186	102·9	8·088	101·6	7·994	100·4	7·901	99·29
51	9·233	131·0	9·104	129·2	8·979	127·4	8·860	125·7	8·745	124·1	8·635	122·5	8·529	121·0	8·426	119·5	8·327	118·1	8·232	116·8
54			9·461	150·5	9·331	148·4	9·207	146·4	9·088	144·5	8·974	142·7	8·863	141·0	8·756	139·3	8·653	137·6	8·554	136·0
57									9·423	167·0	9·304	164·9	9·190	162·8	9·079	160·9	8·972	159·0	8·869	157·2
60															9·394	184·5	9·284	182·3	9·178	180·3

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	225		230		235		240		245		250		255		260		265		270	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
3	·9462	·0465	·9357	·0459	·9256	·0454	·9157	·0449	·9062	·0445	·8969	·0440	·8880	·0436	·8793	·0431	·8708	·0427	·8626	·0423
4	1·203	·1050	1·190	·1039	1·177	·1027	1·165	·1016	1·153	·1006	1·141	·0996	1·129	·0986	1·118	·0976	1·108	·0967	1·097	·0957
5	1·446	·1971	1·430	·1949	1·414	·1928	1·399	·1908	1·384	·1888	1·370	·1869	1·356	·1850	1·343	·1831	1·331	·1814	1·318	·1797
6	1·676	·3290	1·657	·3253	1·639	·3218	1·622	·3184	1·605	·3151	1·589	·3119	1·573	·3088	1·557	·3058	1·542	·3028	1·528	·2999
7	1·895	·5065	1·874	·5009	1·854	·4955	1·834	·4902	1·815	·4851	1·797	·4802	1·779	·4754	1·762	·4708	1·745	·4663	1·728	·4619
8	2·106	·7353	2·083	·7271	2·061	·7193	2·039	·7117	2·018	·7043	1·997	·6971	1·977	·6902	1·958	·6834	1·939	·6769	1·921	·6705
9	2·310	·1021	2·284	1·009	2·260	·9984	2·236	·9878	2·213	·9775	2·190	·9677	2·168	·9580	2·147	·9487	2·127	·9396	2·107	·9307
10	2·507	1·367	2·479	1·352	2·453	1·338	2·427	1·323	2·401	1·310	2·377	1·296	2·353	1·284	2·330	1·271	2·308	1·259	2·286	1·247
11	2·698	1·780	2·668	1·761	2·639	1·742	2·612	1·723	2·584	1·705	2·558	1·688	2·533	1·671	2·508	1·655	2·484	1·639	2·461	1·624
12	2·884	2·265	2·852	2·240	2·821	2·216	2·791	2·192	2·762	2·169	2·734	2·147	2·707	2·126	2·680	2·105	2·655	2·085	2·630	2·066
13	3·065	2·825	3·031	2·793	2·998	2·763	2·966	2·734	2·935	2·706	2 906	2·678	2·877	2·652	2·849	2·626	2·822	2·602	2·796	2·576
14	3·241	3·456	3·205	3·418	3·170	3·381	3·137	3·345	3·104	3·311	3·072	3·277	3·042	3·244	3·012	3·212	2·984	3·182	2·956	3·152
15	3·413	4·188	3·375	4·142	3·339	4·097	3·304	4·054	3·270	4·012	3·236	3·971	3·204	3·931	3·173	3·893	3·143	3·856	3·113	3·820
16	3·581	5·000	3·541	4·945	3·503	4·891	3·466	4·839	3·430	4·789	3·396	4·741	3·362	4·694	3·329	4·648	3·297	4·604	3·266	4·561
17	3·754	5·918	3·713	5·852	3·673	5·789	3·634	5·728	3·596	5·669	3·560	5·612	3·525	5·556	3·490	5·502	3·457	5·449	3·425	5·398
18	3·907	6·904	3·864	6·828	3·822	6·755	3·782	6·683	3·743	6·614	3·705	6·547	3·668	6·482	3·632	6·419	3·597	6·358	3·564	6·298
19	4·075	8·023	4·030	7·935	3·987	7·849	3·945	7·766	3·904	7·686	3·864	7·608	3·826	7·533	3·789	7·460	3·752	7·388	3·717	7·319
20	4·221	9·209	4·174	9·107	4·129	9·009	4·086	8·914	4·044	8·822	4·003	8·733	3·963	8·646	3·924	8·562	3·887	8·480	3·851	8·400
21	4·373	10·52	4·325	10·40	4·279	10·29	4·234	10·18	4·190	10·08	4·148	9·976	4·107	9·877	4·067	9·781	4·028	9·688	3·990	9·597
22	4·524	11·94	4·474	11·81	4·426	11·68	4·379	11·56	4·334	11·44	4·290	11·33	4·247	11·21	4·206	11·10	4·166	10·99	4·127	10·89
23	4·671	13·48	4·620	13·33	4·570	13·19	4·522	13·05	4·475	12·91	4·430	12·78	4·386	12·66	4·344	12·53	4·302	12·41	4·262	12·30
24	4·817	15·13	4·764	14·97	4·713	14·81	4·663	14·65	4·614	14·50	4·568	14·35	4·523	14·21	4·479	14·07	4·436	13·94	4·394	13·81
26	5·101	18·81	5·045	18·60	4·991	18·40	4·938	18·21	4·887	18·02	4·838	17·83	4·790	17·66	4·743	17·49	4·698	17·32	4·654	17·16
27	5·240	20·84	5·182	20·61	5·127	20·38	5·073	20·17	5·020	19·96	4·970	19·76	4·920	19·56	4·873	19·37	4·826	19·19	4·781	19·01
30	5·646	27·72	5·584	27·41	5·524	27·12	5·466	26·83	5·409	26·55	5·355	26·29	5·301	26·02	5·250	25·77	5·200	25·53	5·151	25·29
33	6·037	35·86	5·971	35·46	5·906	35·08	5·844	34·71	5·784	34·35	5·726	34·01	5·669	33·67	5·614	33·34	5·560	33·03	5·508	32·72
36	6·414	45·34	6·344	44·84	6·276	44·36	6·209	43·89	6·145	43·44	6·084	43·00	6·023	42·57	5·965	42·16	5·908	41·76	5·853	41·37
39	6·779	56·24	6·705	55·63	6·633	55·03	6·563	54·45	6·495	53·89	6·430	53·34	6·366	52·81	6·304	52·30	6·244	51·80	6·186	51·32
42	7·133	68·63	7·055	67·88	6·979	67·15	6·906	66·44	6·835	65·76	6·766	65·10	6·699	64·45	6·634	63·83	6·571	63·22	6·510	62·63
[illegible]	[illegible]	[illegible]	[illegible]	81·68	7·316	80·81	7·239	79·96	7·165	79·13	7·093	78·33	7·022	77·56	6·954	76·81	6·888	76·08	6·824	75·37

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	225		230		235		240		245		250		255		260		265		270	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
48	7·813	98·18	7·727	97·10	7·644	96·06	7·564	95·05	7·486	94·07	7·411	93·12	7·337	92·20	7·266	91·31	7·197	90·44	7·130	89·59
51	8·139	115·5	8·050	114·2	7·964	113·0	7·880	111·8	7·799	110·6	7·720	109·5	7·644	108·4	7·570	107·4	7·498	106·4	7·428	105·4
54	8·459	134·5	8·366	133·0	8·276	131·6	8·189	130·2	8·105	128·9	8·023	127·6	7·943	126·3	7·866	125·1	7·792	123·9	7·719	122·7
57	8·770	155·4	8·674	153·7	8·581	152·1	8·491	150·5	8·422	149·2	8·318	147·4	8·236	145·9	8·157	144·5	8·080	143·1	8·004	141·8
60	9·075	178·2	8·975	176·2	8·879	174·3	8·786	172·5	8·696	170·7	8·608	169·0	8·523	167·3	8·440	165·7	8·360	164·1	8·282	162·6
63	9·373	202·9	9·271	200·6	9·172	198·5	9·075	196·5	8·981	194·4	8·890	192·5	8·802	190·6	8·717	188·7	8·635	186·9	8·555	185·2
66					9·458	224·7	9·358	222·3	9·262	220·0	9·169	217·8	9·078	215·7	8·990	213·6	8·905	211·6	8·822	209·6
69													9·348	242·7	9·257	240·4	9·169	238·1	9·084	235·9
72																	9·429	266·6	9·341	264·1

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	275		280		285		290		295		300		305		310		315		320	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
3	·8546	·0420	·8468	·0416	·8392	·0411	·8318	·0408	·8246	·0404	·8176	·0401	·8107	·0398	·8040	·0394	·7975	·0391	·7911	·0388
4	1·087	·0949	1·077	·0940	1·067	·0931	1·058	·0923	1·049	·0915	1·040	·0907	1·031	·0900	1·023	·0892	1·014	·0885	1·006	·0878
5	1·306	·1780	1·294	·1764	1·282	·1748	1·271	·1733	1·260	·1718	1·249	·1703	1·239	·1689	1·228	·1675	1·218	·1662	1·208	·1648
6	1·514	·2972	1·500	·2945	1·486	·2918	1·473	·2893	1·460	·2868	1·448	·2843	1·436	·2819	1·424	·2796	1·413	·2774	1·401	·2752
7	1·712	·4576	1·697	·4535	1·681	·4494	1·667	·4454	1·652	·4406	1·638	·4379	1·624	·4342	1·611	·4306	1·598	·4272	1·585	·4237
8	1·903	·6643	1·886	·6583	1·869	·6524	1·852	·6466	1·836	·6411	1·821	·6356	1·806	·6303	1·791	·6252	1·767	·6201	1·762	·6152
9	2·087	·9221	2·068	·9137	2·049	·9056	2·031	·8976	2·014	·8899	1·997	·8824	1·980	·8750	1·964	·8678	1·948	·8608	1·932	·8540
10	2·265	1·235	2·245	1·224	2·224	1·213	2·205	1·202	2·186	1·192	2·167	1·182	2·149	1·172	2·132	1·162	2·215	1·153	2·098	1·144
11	2·438	1·609	2·416	1·594	2·394	1·580	2·373	1·566	2·353	1·553	2·333	1·539	2·313	1·526	2·294	1·514	2·276	1·502	2·258	1·490
12	2·606	2·047	2·582	2·028	2·559	2·009	2·536	1·992	2·514	1·975	2·493	1·958	2·472	1·942	2·452	1·926	2·432	1·910	2·413	1·895
13	2·770	2·552	2·744	2·529	2·719	2·506	2·695	2·484	2·672	2·463	2·650	2·442	2·627	2·422	2·606	2·402	2·586	2·383	2·565	2·364
14	2·928	3·123	2·903	3·095	2·876	3·067	2·851	3·040	2·826	3·014	2·803	2·989	2·779	2·964	2·756	2·940	2·734	2·916	2·712	2·893
15	3·084	3·785	3·056	3·750	3·028	3·717	3·002	3·684	2·976	3·652	2·951	3·621	2·927	3·591	2·903	3·562	2·880	3·534	2·857	3·505
16	3·236	4·519	3·207	4·478	3·178	4·438	3·150	4·399	3·123	4·361	3·096	4·323	3·071	4·288	3·046	4·253	3·021	4·219	2·997	4·185
17	3·393	5·348	3·362	5·300	3·332	5·252	3·303	5·206	3·275	5·162	3·248	5·119	3·220	5·076	3·194	5·034	3·168	4·994	3·143	4·954
18	3·531	6·240	3·499	6·184	3·468	6·129	3·437	6·075	3·408	6·023	3·379	5·972	3·351	5·922	3·324	5·874	3·297	5·827	3·271	5·780
19	3·683	7·251	3·649	7·185	3·617	7·121	3·585	7·059	3·554	6·999	3·524	6·940	3·495	6·882	3·467	6·826	3·439	6·771	3·412	6·717
20	3·815	8·323	3·780	8·248	3·746	8·175	3·714	8·104	3·682	8·034	3·651	7·966	3·621	7·900	3·591	7·835	3·562	7·772	3·534	7·710
21	3·953	9·508	3·917	9·422	3·882	9·338	3·848	9·257	3·815	9·277	3·783	9·100	3·752	9·025	3·721	8·951	3·691	8·879	3·662	8·809

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in inches.	Sine of Inclination. (1 over:—)																			
	275		280		285		290		295		300		305		310		315		320	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
22	4·089	10·79	4·052	10·69	4·015	10·60	3·980	10·50	3·946	10·41	3·913	10·33	3·881	10·24	3·849	10·16	3·818	10·08	3·788	9·999
23	4·223	12·18	4·185	12·07	4·147	11·96	4·111	11·86	4·075	11·75	4·041	11·66	4·017	11·56	3·975	11·46	3·943	11·37	3·911	11·28
24	4·354	13·68	4·314	13·55	4·276	13·43	4·238	13·31	4·202	13·20	4·167	13·09	4·132	12·98	4·098	12·87	4·065	12·77	4·033	12·67
26	4·611	17·00	4·569	16·84	4·528	16·69	4·489	16·55	4·450	16·41	4·413	16·27	4·376	16·13	4·340	16·00	4·306	15·87	4·272	15·75
27	4·737	18·83	4·694	18·66	4·652	18·49	4·611	18·33	4·572	18·18	4·533	18·02	4·496	17·87	4·459	17·73	4·423	17·59	4·388	17·45
30	5·104	25·05	5·058	24·82	5·013	24·60	4·969	24·39	4·927	24·18	4·885	23·98	4·844	23·78	4·804	23·58	4·766	23·39	4·729	23·21
33	5·458	32·42	5·408	32·12	5·360	31·83	5·314	31·56	5·268	31·29	5·223	31·02	5·180	30·77	5·138	30·51	5·097	30·27	5·057	30·03
36	5·799	40·99	5·747	40·62	5·695	40·26	5·645	39·91	5·597	39·57	5·550	39·23	5·504	38·90	5·459	38·59	5·416	38·28	5·373	37·98
39	6·129	50·85	6·074	50·39	6·020	49·94	5·968	49·50	5·917	49·08	5·867	48·67	5·818	48·26	5·770	47·87	5·724	47·49	5·679	47·11
42	6·450	62·05	6·391	61·49	6·334	60·94	6·279	60·41	6·226	59·90	6·174	59·39	6·123	58·90	6·073	58·42	6·024	57·95	5·977	57·50
45	6·761	74·67	6·700	74·00	6·640	73·34	6·582	72·70	6·526	72·08	6·472	71·47	6·418	70·88	6·366	70·31	6·315	69·74	6·265	69·19
48	7·065	88·77	7·001	87·97	6·939	87·16	6·878	86·43	6·819	85·69	6·762	84·97	6·705	84·26	6·652	83·58	6·598	82·92	6·546	82·26
51	7·360	104·4	7·293	103·5	7·228	102·5	7·165	101·6	7·101	100·7	7·045	99·94	6·986	99·11	6·929	98·30	6·874	97·52	6·820	96·75
54	7·648	121·6	7·579	120·5	7·512	119·5	7·447	118·4	7·384	117·4	7·321	116·4	7·260	115·4	7·201	114·5	7·144	113·6	7·088	112·7
57	7·930	140·5	7·859	139·2	7·789	138·0	7·721	136·8	7·655	135·6	7·591	134·5	7·528	133·4	7·467	132·3	7·407	131·2	7·349	130·2
60	8·206	161·1	8·132	159·6	8·060	158·2	7·990	156·8	7·922	155·5	7·855	154·2	7·790	152·9	7·727	151·7	7·665	150·5	7·605	149·3
63	8·477	183·5	8·400	181·8	8·325	180·2	8·252	178·6	8·182	177·1	8·114	175·6	8·047	174·2	7·981	172·8	7·917	171·4	7·855	170·0
66	8·741	207·7	8·662	205·8	8·585	204·0	8·511	202·2	8·438	200·4	8·368	198·7	8·298	197·1	8·231	195·5	8·165	193·9	8·101	192·4
69	9·001	233·7	8·920	231·6	8·841	229·5	8·764	227·5	8·689	225·6	8·616	223·7	8·545	221·9	8·475	220·0	8·407	218·3	8·341	216·6
72	9·255	261·7	9·172	259·3	9·091	257·0	9·012	254·8	8·935	252·6	8·860	250·5	8·787	248·4	8·715	246·3	8·646	244·4	8·578	242·5
78											9·336	309·7	9·259	307·2	9·183	304·7	9·110	302·3	9·038	299·9

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	325		330		335		340		345		350		355		360		365		370	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
3	·7849	·0385	·7788	·0382	·7728	·0379	·7670	·0376	·7613	·0373	·7558	·0371	·7503	·0368	·7450	·0365	·7397	·0363	·7346	·0360
4	·9985	·0871	·9907	·0864	·9832	·0858	·9758	·0851	·9686	·0845	·9615	·0839	·9545	·0833	·9478	·0827	·9411	·0821	·9346	·0815
5	1·199	·1635	1·190	·1622	1·181	·1610	1·172	·1598	1·163	·1586	1·155	·1575	1·146	·1563	1·138	·1552	1·130	·1541	1·122	·1531
6	1·390	·2730	1·379	·2709	1·369	·2688	1·359	·2668	1·349	·2648	1·339	·2629	1·329	·2610	1·320	·2592	1·310	·2573	1·301	·2556
7	1·573	·4204	1·561	·4172	1·549	·4140	1·537	·4109	1·526	·4079	1·515	·4049	1·504	·4020	1·493	·3991	1·483	·3963	1·472	·3936
8	1·748	·6103	1·735	·6056	1·722	·6010	1·709	·5965	1·696	·5921	1·684	·5878	1·672	·5836	1·660	·5795	1·648	·5754	1·637	·5714
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·888	·8343	1·874	·8281	1·860	·8220	1·847	·8160	1·833	·8101	1·820	·8052	1·808	·7988	1·795	·7933

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	325		330		335		340		345		350		355		360		365		370	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
10	2·081	1·135	2·065	1·126	2·049	1·118	2·034	1·109	2·019	1·101	2·004	1·093	1·990	1·085	1·976	1·077	1·962	1·070	1·949	1·063
11	2·240	1·478	2·223	1·467	2·205	1·456	2·189	1·445	2·173	1·434	2·157	1·424	2·142	1·413	2·127	1·403	2·112	1·394	2·097	1·384
12	2·394	1·880	2·376	1·866	2·358	1·852	2·340	1·838	2·323	1·824	2·306	1·811	2·289	1·798	2·273	1·785	2·258	1·773	2·243	1·761
13	2·544	2·345	2·525	2·327	2·506	2·310	2·487	2·293	2·469	2·276	2·451	2·259	2·433	2·243	2·416	2·227	2·399	2·211	2·383	2·196
14	2·691	2·870	2·670	2·848	2·650	2·826	2·630	2·805	2·611	2·785	2·592	2·765	2·573	2·745	2·555	2·726	2·537	2·705	2·520	2·688
15	2·834	3·478	2·812	3·451	2·791	3·425	2·770	3·399	2·750	3·374	2·730	3·350	2·710	3·326	2·691	3·302	2·672	3·279	2·654	3·257
16	2·974	4·153	2·951	4·121	2·929	4·090	2·907	4·059	2·885	4·029	2·865	4·000	2·844	3·971	2·824	3·943	2·804	3·916	2·785	3·889
17	3·119	4·915	3·095	4·877	3·071	4·841	3·048	4·804	3·025	4·769	3·003	4·734	2·982	4·701	2·961	4·668	2·940	4·635	2·920	4·603
18	3·245	5·735	3·220	5·691	3·196	5·648	3·172	5·605	3·149	5·565	3·126	5·524	3·104	5·485	3·082	5·446	3·050	5·408	3·039	5·371
19	3·385	6·665	3·359	6·614	3·333	6·564	3·308	6·515	3·284	6·467	3·260	6·420	3·237	6·374	3·214	6·329	3·192	6·285	3·170	6·242
20	3·506	7·650	3·479	7·591	3·453	7·534	3·427	7·478	3·302	7·423	3·377	7·369	3·353	7·316	3·330	7·265	3·306	7·214	3·284	7·164
21	3·633	8·740	3·605	8·672	3·578	8·607	3·551	8·543	3·525	8·480	3·500	8·419	3·475	8·359	3·450	8·300	3·426	8·242	3·403	8·186
22	3·758	9·921	3·729	9·845	3·701	9·771	3·674	9·698	3·647	9·627	3·620	9·557	3·594	9·489	3·569	9·422	3·544	9·357	3·520	9·293
23	3·881	11·19	3·851	11·11	3·822	11·02	3·794	10·94	3·766	10·86	3·738	10·78	3·712	10·71	3·686	10·63	3·660	10·56	3·635	10·48
24	4·002	12·57	3·971	12·47	3·941	12·38	3·912	12·29	3·883	12·20	3·855	12·11	3·828	12·02	3·801	11·94	3·774	11·86	3·748	11·78
26	4·239	15·62	4·206	15·50	4·174	15·39	4·143	15·27	4·113	15·16	4·083	15·05	4·054	14·94	4·025	14·84	3·997	14·73	3·970	14·63
27	4·364	17·31	4·321	17·18	4·288	17·05	4·256	16·92	4·225	16·80	4·195	16·67	4·165	16·56	4·136	16·44	4·107	16·32	4·079	16·21
30	4·692	23·03	4·656	22·85	4·621	22·68	4·587	22·51	4·453	22·35	4·520	22·18	4·488	22·03	4·456	21·87	4·425	21·72	4·395	21·57
33	5·017	29·80	4·979	29·57	4·941	29·35	4·904	29·13	4·868	28·91	4·833	28·71	4·799	28·50	4·765	28·30	4·732	28·10	4·700	27·91
36	5·331	37·68	5·290	37·39	5·250	37·11	5·211	35·83	5·173	36·56	5·136	36·30	5·099	36·04	5·063	35·79	5·028	35·54	4·994	35·30
39	5·635	46·74	5·592	46·39	5·550	46·04	5·508	45·69	5·468	45·36	5·429	45·03	5·390	44·71	5·352	44·40	5·315	44·09	5·279	43·79
42	5·930	57·05	5·885	56·61	5·840	56·19	5·798	55·77	5·754	55·36	5·713	54·96	5·672	54·57	5·632	54·19	5·593	53·82	5·555	53·45
45	6·216	68·66	6·169	68·13	6·123	67·62	6·077	67·11	6·032	66·62	5·989	66·14	5·946	65·67	5·904	65·21	5·864	64·76	5·824	64·32
48	6·495	81·62	6·445	81·00	6·397	80·39	6·349	79·79	6·303	79·21	6·257	78·64	6·213	78·08	6·170	77·53	6·127	76·99	6·085	76·47
51	6·767	96·00	6·715	95·26	6·665	94·55	6·615	93·85	6·567	93·16	6·519	92·49	6·473	91·83	6·428	91·19	6·383	90·56	6·340	89·94
54	7·032	111·8	6·979	111·0	6·927	110·2	6·875	109·3	6·824	108·5	6·775	107·8	6·727	107·0	6·680	106·2	6·634	105·5	6·589	104·8
57	7·292	129·2	7·236	128·2	7·182	127·2	7·128	126·3	7·076	125·4	7·025	124·5	6·976	123·6	6·927	122·7	6·879	121·9	6·832	121·0
60	7·546	148·1	7·488	147·0	7·432	145·9	7·377	144·8	7·323	143·7	7·270	142·7	7·218	141·7	7·168	140·7	7·118	139·7	7·070	138·8
63	7·794	168·7	7·734	167·4	7·677	166·1	7·620	164·9	7·564	163·7	7·510	162·5	7·457	161·4	7·404	160·2	7·353	159·1	7·303	158·1
66	8·038	190·9	7·976	189·5	7·916	188·0	7·858	186·7	7·801	185·3	7·745	183·9	7·689	182·6	7·635	181·4	7·583	180·1	7·531	178·9
69	8·276	214·9	8·213	213·2	8·152	211·6	8·091	210·1	8·032	208·5	7·974	207·0	7·918	205·5	7·863	204·1	7·808	202·7	7·755	201·3

TABLE 56 (Continued).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

Circular Sewers, Pipes and Conduits.—Running Full. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	325		330		335		340		345		350		355		360		365		370	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
72	8·511	240·6	8·446	238·7	8·383	237·0	8·321	235·2	8·260	233·5	8·201	231·8	8·142	230·2	8·086	228·6	8·030	227·0	7·975	225·5
78	8·968	297·6	8·900	295·3	8·833	293·1	8·768	290·9	8·704	288·9	8·641	286·7	8·580	284·7	8·520	282·7	8·461	280·7	8·404	278·8
84	9·411	362·2	9·339	359·4	9·269	356·7	9·200	354·0	9·133	351·5	9·068	349·0	9·003	346·5	8·940	344·1	8·879	341·7	8·819	339·4
90													9·414	415·9	9·348	413·0	9·284	410·1	9·221	407·4

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	375		380		385		390		395		400		405		410		415		420	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
3	·7296	·0358																		
4	·9283	·0810	·9220	·0804	·9158	·0799	·9098	·0794	·9039	·0788	·8981	·0783	·8924	·0778	·8869	·0773	·8814	·0769	·8760	·0764
5	1·115	·1520	1·107	·1510	1·100	·1500	1·093	·1490	1·086	·1480	1·079	·1471	1·072	·1462	1·066	·1453	1·059	·1444	1·052	·1434
6	1·293	·2538	1·284	·2521	1·275	·2504	1·267	·2488	1·259	·2472	1·251	·2456	1·243	·2440	1·235	·2425	1·228	·2411	1·220	·2396
7	1·462	·3909	1·453	·3883	1·443	·3857	1·434	·3832	1·424	·3807	1·415	·3783	1·406	·3759	1·397	·3735	1·389	·3712	1·380	·3690
8	1·626	·5676	1·615	·5637	1·604	·5600	1·593	·5563	1·583	·5527	1·573	·5492	1·563	·5458	1·553	·5424	1·543	·5390	1·534	·5357
9	1·783	·7899	1·771	·7826	1·759	·7774	1·748	·7724	1·737	·7674	1·726	·7625	1·715	·7577	1·704	·7530	1·694	·7484	1·683	·7438
10	1·935	1·055	1·922	1·048	1·910	1·041	1·897	1·035	1·885	1·028	1·873	1·021	1·861	1·015	1·849	1·008	1·838	1·028	1·827	·9967
11	2·083	1·375	2·069	1·365	2·055	1·356	2·042	1·348	2·029	1·339	2·016	1·331	2·003	1·322	1·991	1·313	1·979	1·305	1·967	1·298
12	2·228	1·750	2·212	1·738	2·197	1·726	2·183	1·714	2·169	1·703	2·155	1·692	2·141	1·681	2·128	1·671	2·115	1·661	2·102	1·651
13	2·366	2·181	2·351	2·167	2·335	2·152	2·320	2·138	2·305	2·125	2·290	2·111	2·276	2·098	2·262	2·085	2·248	2·072	2·234	2·059
14	2·503	2·669	2·486	2·652	2·470	2·634	2·454	2·617	2·438	2·600	2·422	2·583	2·407	2·567	2·392	2·551	2·378	2·536	2·363	2·520
15	2·636	3·235	2·618	3·213	2·601	3·192	2·584	3·171	2·567	3·151	2·551	3·131	2·535	3·111	2·519	3·092	2·504	3·073	2·489	3·054
16	2·766	3·862	2·748	3·837	2·730	3·811	2·712	3·786	2·694	3·662	2·677	3·738	2·660	3·714	2·644	3·691	2·628	3·669	2·612	3·647
17	2·900	4·572	2·881	4·542	2·862	4·512	2·843	4·482	2·825	4·453	2·807	4·425	2·790	4·397	2·772	4·370	2·755	4·343	2·739	4·317
18	3·019	5·335	2·999	5·299	2·979	5·264	2·959	5·230	2·940	5·196	2·922	5·163	2·903	5·131	2·885	5·100	2·868	5·068	2·850	5·037
19	3·149	6·200	3·128	6·158	3·107	6·118	3·087	6·078	3·067	6·039	3·047	6·001	3·028	5·963	3·009	5·926	2·991	5·890	2·973	5·854
20	3·262	7·116	3·240	7·069	3·219	7·023	3·198	6·977	3·177	6·932	3·157	6·888	3·137	6·845	3·118	6·803	3·099	6·761	3·080	6·720
21	3·380	8·130	3·357	8·076	3·335	8·023	3·314	7·971	3·292	7·919	3·271	7·869	3·251	7·820	3·231	7·772	3·211	7·724	3·192	7·677
22	3·496	9·230	3·473	9·168	3·450	9·108	3·427	9·049	3·405	8·991	3·384	8·934	3·363	8·878	3·342	8·823	3·322	8·769	3·301	8·716
23	3·610	10·41	3·586	10·34	3·563	10·28	3·540	10·21	3·517	10·14	3·495	10·08	3·473	10·02	3·451	9·959	3·430	9·898	3·409	9·838
24	3·723	11·70	3·698	11·62	3·674	11·54	3·650	11·46	3·627	11·39	3·603	11·32	3·580	11·25	3·558	11·18	3·537	11·11	3·516	11·04
26	3·943	14·54	3·917	14·43	3·891	14·34	3·865	14·25	3·817	14·07	3·817	14·07	3·793	13·98	3·769	13·89	3·746	13·81	3·724	13·73
27	4·051	16·10	4·024	16·00	3·998	15·89	3·972	15·79	3·946	15·69	3·921	15·59	3·897	15·49	3·873	15·39	3·849	15·30	3·825	15·21

Circular Sewers, Pipes and Conduits.—Running Full. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Sine of Inclination. (1 over:—)

Diameter in Inches.	375		380		385		390		395		400		405		410		415		420	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
30	4·365	21·43	4·336	21·29	4·308	21·15	4·280	21·01	4·252	20·87	4·225	20·74	4·199	20·61	4·173	20·48	4·148	20·35	4·123	20·23
33	4·668	27·72	4·637	27.54	4·606	27·36	4·577	27·18	4·548	27·60	4·519	26·84	4·491	26·67	4·463	26·53	4·435	26·36	4·409	26·19
36	4·960	35·06	4·927	34·83	4·895	34·60	4·863	34·37	4·832	34·15	4·802	33·94	4·771	33·73	4·742	33·52	4·713	33·31	4·685	33·11
39	5·243	43·50	5·208	43·21	5·174	42·92	5·141	42·64	5·108	42·37	5·076	42·10	5·044	41·84	5·013	41·58	4·982	41·35	4·952	41·08
42	5·518	53·09	5·481	52·74	5·445	52·39	5·410	52·05	5·375	51·71	5·341	51·39	5·307	51·07	5·275	50·75	5·243	50·44	5·212	50·14
45	5·784	63·89	5·746	63·46	5·708	63·05	5·671	62·64	5·635	62·24	5·600	61·85	5·565	61·46	5·531	61·08	5·497	60·71	5·464	60·34
48	6·044	75·95	6·004	75·45	5·965	74·95	5·926	74·47	5·888	73·99	5·851	73·53	5·814	73·07	5·779	72·62	5·744	72·18	5·709	71·74
51	6·297	89·34	6·255	88·74	6·214	88·16	6·174	87·59	6·135	87·03	6·096	86·48	6·058	85·95	6·008	85·42	5·984	84·90	5·948	84·39
54	6·544	104·1	6·501	103·4	6·458	102·7	6·417	102·0	6·376	101·4	6·336	100·7	6·296	100·1	6·257	99·52	6·219	98·91	6·182	98·32
57	6·786	120·2	6·741	119·4	6·697	118·6	6·653	117·9	6·611	117·1	6·569	116·4	6·528	115·7	6·488	115·0	6·449	114·2	6·410	113·6
60	7·023	137·8	6·976	136·9	6·930	136·0	6·885	135·2	6·841	134·3	6·798	133·4	6·756	132·6	6·715	131·8	6·674	131·0	6·633	130·2
63	7·254	157·0	7·206	156·0	7·158	154·9	7·112	153·9	7·061	152·9	7·022	152·0	6·978	151·0	6·936	150·1	6·893	149·2	6·852	148·3
66	7·481	177·7	7·431	176·5	7·382	175·4	7·335	174·2	7·288	173·1	7·242	172·0	7·197	170·9	7·153	169·9	7·109	168·9	7·067	167·9
69	7·703	200·0	7·652	198·7	7·602	197·4	7·553	196·1	7·505	194·8	7·457	193·6	7·411	192·4	7·366	191·2	7.321	190·1	7·277	188·9
72	7·922	223·9	7·869	222·5	7·818	221·0	7·767	219·6	7·718	218·2	7·669	216·8	7·622	215·5	7·575	214·1	7·529	212·8	7·483	211·6
78	8·348	277·0	8·292	275·2	8·238	273·4	8·185	271·6	8·133	269·9	8·082	268·2	8·031	266·5	7·982	264·8	7·933	263·2	7·886	261·6
84	8·759	337·1	8·701	334·9	8·645	332·7	8·589	330·5	8·534	328·4	8·480	326·3	8·427	324·3	8·376	322·3	8·325	320·3	8·275	318·4
90	9·159	404·6	9·098	402·0	9·039	399·3	8·981	396·8	8·923	394·2	8·867	391·7	8·812	389·3	8·758	386·9	8·705	384·5	8·653	382·2
96							9·361	470·5	9·301	467·5	9·242	464·5	9·185	461·7	9·129	458·8	9·073	456·0	9·019	453·3
102																			9·376	532·0

Sine of Inclination. (1 over:—)

Diameter in Inches.	425		430		435		440		445		450		455		460		465		470	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
4	·8707	·0759	·8655	·0755	·8603	·0750	·8553	·0746	·8504	·0742	·8456	·0736	·8408	·0733	·8361	·0729	·8315	·0725	·8269	·0721
5	1·046	·1426	1·039	·1417	1·033	·1409	1·027	·1401	1·021	·1393	1·016	·1385	1·010	·1377	·1004	·1369	·9991	·1362	·9936	·1354
6	1·213	·2381	1·205	·2367	1·198	·2353	1·191	·2340	1·184	·2326	1·178	·2313	1·171	·2300	1·165	·2287	1·158	·2274	1·152	·2262
7	1·372	·3668	1·364	·3646	1·356	·3624	1·348	·3603	1·340	·3582	1·333	·3562	1·325	·3542	1·318	·3522	1·310	·3503	1·303	·3484
8	1·525	·5325	1·516	·5294	1·507	·5262	1·499	·5232	1·490	·5202	1·481	·5172	1·473	·5143	1·465	·5115	1·457	·5086	1·449	·5059
9	1·673	·7393	1·663	·7349	1·653	·7306	1·643	·7264	1·634	·7222	1·625	·7181	1·616	·7140	1·607	·7101	1·598	·7062	1·589	·7023
10	1·816	·9907	1·805	·9848	1·795	·9790	1·784	·9734	1·774	·9677	1·764	·9623	1·754	·9569	1·744	·9516	1·735	·9463	1·725	·9412
11	1·955	1·290	1·943	1·282	1·932	1·275	1·921	1·267	1·910	1·260	1·899	1·253	1·888	1·246	1·878	1·239	1·867	1·232	1·857	1·225

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—) 425		430		435		440		445		450		455		460		465		470	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
12	2·090	1·641	2·077	1·631	2·065	1·622	2·054	1·613	2·042	1·603	2·030	1·594	2·018	1·585	2·007	1·576	1·996	1·568	1·985	1·559
13	2·221	2·047	2·208	2·035	2·195	2·023	2·182	2·011	2·170	2·000	2·157	1·988	2·145	1·977	2·133	1·966	2·122	1·956	2·110	1·945
14	2·349	2·505	2·335	2·490	2·321	2·476	2·308	2·461	2·295	2·447	2·282	2·433	2·269	2·420	2·256	2·406	2·244	2·393	2·232	2·380
15	2·474	3·036	2·459	3·018	2·445	3·000	2·431	2·983	2·417	2·966	2·403	2·949	2·390	2·933	2·376	2·916	2·363	2·900	2·351	2·885
16	2·596	3·625	2·581	3·604	2·507	3·583	2·551	3·562	2·536	3·541	2·522	3·521	2·508	3·502	2·494	3·482	2·480	3·463	2·466	3·445
17	2·722	4·291	2·705	4·266	2·690	4·241	2·675	4·216	2·659	4·192	2·644	4·169	2·630	4·145	2·615	4·122	2·601	4·100	2·587	4·078
18	2·833	5·004	2·817	4·978	2·800	4·949	2·784	4·920	2·768	4·892	2·752	4·864	2·737	4·837	2·722	4·810	2·707	4·784	2·692	4·758
19	2·955	5·819	2·938	5·785	2·921	5·751	2·904	5·718	2·887	5·685	2·871	5·653	2·855	5·621	2·839	5·590	2·824	5·560	2·808	5·530
20	3·061	6·680	3·043	6·640	3·026	6·601	3·008	6·563	2·991	6·526	2·974	6·489	2·958	6·453	2·941	6·417	2·925	6·382	2·909	6·347
21	3·173	7·631	3·154	7·586	3·135	7·542	3·117	7·499	3·099	7·456	3·082	7·414	3·065	7·372	3·048	7·332	3·031	7·292	3·015	7·252
22	3·282	8·664	3·262	8·613	3·243	8·562	3·225	8·513	3·206	8·464	3·188	8·417	3·170	8·369	3·153	8·323	3·136	8·278	3·199	8·233
23	3·389	9·779	3·369	9·721	3·349	9·665	3·330	9·609	3·311	9·554	3·292	9·500	3·274	9·447	3·256	9·395	3·238	9·344	3·221	9·293
24	3·495	10·98	3·474	10·91	3·454	10·85	3·434	10·79	3·414	10·72	3·395	10·66	3·376	10·60	3·358	10·34	3·339	10·49	3·321	10·43
26	3·701	13·64	3·680	13·56	3·658	13·49	3·637	13·41	3·616	13·33	3·596	13·26	3·576	13·18	3·556	13·11	3·537	13·04	3·518	12·97
27	3·803	15·12	3·780	15·03	3·758	14·94	3·737	14·85	3·715	14·77	3·694	14·69	3·674	14·60	3·653	14·52	3·634	14·44	3·614	14·37
30	4·098	20·11	4·073	20·00	4·050	19·88	4·027	19·76	4·004	19·65	3·981	19·54	3·959	19·43	3·937	19·33	3·916	19·22	3·895	19·12
33	4·382	26·03	4·357	25·87	4·331	25·72	4·305	25·57	4·281	25·43	4·258	25·29	4·234	25·15	4·211	25·01	4·188	24·87	4·165	24·74
36	4·657	32·92	4·629	32·72	4·603	32·53	4·576	32·35	4·550	32·16	4·525	31·98	4·510	31·80	4·475	31·63	4·502	31·46	4·426	31·29
39	4·923	40·84	4·894	40·60	4·865	40·36	4·837	40·13	4·810	39·90	4·783	39·68	4·756	39·46	4·730	39·24	4·704	39·03	4·679	38·82
42	5·181	49·84	5·150	49·55	5·120	49·26	5·091	48·98	5·062	48·70	5·033	48·43	5·005	48·16	4·978	47·89	4·951	47·63	4·924	47·38
45	5·431	59·99	5·399	59·63	5·368	59·29	5·337	58·95	5·307	58·61	5·277	58·28	5·148	57·96	5·219	57·64	5·190	57·33	5·163	57·02
48	5·675	71·32	5·642	70·90	5·609	70·49	5·577	70·08	5·545	69·68	5·514	69·29	5·483	68·91	5·453	68·53	5·424	68·16	5·394	67·79
51	5·913	83·88	5·878	83·39	5·844	82·91	5·811	82·43	5·778	81·96	5·745	81·50	5·713	81·05	5·682	80·61	5·651	80·17	5·621	79·74
54	6·145	97·74	6·109	97·16	6·074	96·60	6·039	96·05	6·004	95·50	5·971	94·96	5·938	94·44	5·905	93·92	5·873	93·41	5·842	92·91
57	6·372	112·9	6·335	112·2	6·298	111·6	6·262	110·9	6·226	110·3	6·191	109·7	6·157	109·5	6·123	108·5	6·090	107·9	6·057	107·3
60	6·953	129·4	6·555	128·7	6·517	127·9	6·480	127·2	6·443	126·5	6·407	125·8	6·372	125·1	6·337	124·4	6·302	123·7	6·269	123·1
63	6·812	147·4	6·772	146·6	6·732	145·7	6·694	144·9	6·656	144·0	6·619	143·2	6·582	142·4	6·546	141·7	6·510	140·9	6·475	140·1
66	7·025	166·9	6·983	165·9	6·943	164·9	6·903	164·0	6·864	163·0	6·826	162·1	6·788	161·2	6·751	160·4	6·714	159·5	6·678	158·6
69	7·234	187·8	7·191	186·7	7·150	185·6	7·109	184·6	7·068	183·5	7·029	182·5	6·990	181·5	6·952	180·5	6·914	179·5	6·877	178·5
72	7·439	210·3	7·395	210·0	7·353	207·9	7·311	206·7	7·269	205·5	7·228	204·3	7·188	203·2	7·149	202·1	7·110	201·0	7·072	199·9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7·660	[illegible]	7·617	252·7	7·575	251·3	7·534	250·0	7·493	248·6	7·453	247·3

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = ·013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—) 425		430		435		440		445		450		455		460		465		470	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
84	8·226	316·5	8·178	314·7	8·131	312·9	8·084	311·1	8·038	309·3	7·993	307·6	7·949	305·9	7·906	304·2	7·863	302·6	7·821	300·9
90	8·601	379·9	8·551	377·7	8·502	375·5	8·453	373·4	8·405	371·3	8·358	369·2	8·312	367·2	8·267	365·2	8·222	363·2	8·178	361·3
96	8·965	450·6	8·913	448·0	8·862	445·4	8·811	442·9	8·761	440·4	8·712	437·9	8·664	435·5	8·617	433·1	8·570	430·8	8·524	428·4
102	9·320	528·8	9·266	525·7	9·212	522·7	9·159	519·7	9·108	516·8	9·057	513·9	9·006	511·1	8·958	508·3	8·909	505·5	8·861	502·8
108															9·290	591·0	9·240	587·8	9·190	584·6

Diameter in Inches.	Sine of Inclination. (1 over:—) 475		480		485		490		495		500		510		520		530		540	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
4	·8225	·0717	·8180	·0713	·8137	·0710	·8094	·0706	·8052	·0702	·8011	·0699	·7930	·0692	·7851	·0685	·7774	·0678	·7699	·0671
5	·9883	·1347	·9830	·1340	·9778	·1333	·9727	·1326	·9676	·1319	·9627	·1312	·9529	·1299	·9435	·1286	·9343	·1273	·9253	·1261
6	1·146	·2250	1·139	·2238	1·133	·2226	1·127	·2214	1·122	·2203	1·116	·2191	1·105	·2169	1·094	·2148	1·083	·2127	1·073	·2107
7	1·296	·3465	1·289	·3447	1·283	·3428	1·276	·3410	1·269	·3393	1·263	·3375	1·250	3341	1·238	·3308	1·226	·3276	1·214	·3245
8	1·441	·5031	1·433	·5005	1·426	·4978	1·418	·4952	1·411	·4927	1·404	·4901	1·390	·4852	1·376	·4804	1·363	·4757	1·350	·4712
9	1·581	·6986	1·572	·6948	1·564	·6912	1·556	·6876	1·548	·6840	1·540	·6805	1·525	·6737	1·509	·6670	1·495	·6605	1·481	·6542
10	1·716	·9361	1·707	·9311	1·698	·9262	1·689	·9214	1·680	·9167	1·672	·9119	1·655	·9028	1·639	·8939	1·623	·8852	1·607	·8768
11	1·847	1·219	1·838	1·212	1·828	1·20[illegible]	1·818	1·200	1·809	1·194	1·800	1·176	1·781	1·175	1·764	1·164	1·747	1·153	1·730	1·142
12	1·975	1·551	1·964	1·543	1·954	1·534	1·944	1·526	1·933	1·518	1·924	1·511	1·904	1·496	1·886	1·481	1·867	1·467	1·850	1·453
13	2·099	1·934	2·088	1·924	2·077	1·914	2·066	1·904	2·055	1·894	2·045	1·885	2·024	1·866	2·004	1·847	1·985	1·829	1·965	1·812
14	2·202	2·368	2·208	2·355	2·197	2·343	2·185	2·331	2·174	2·319	2·163	2·307	2·141	2·284	2·120	2·261	2·099	2·239	2·080	2·219
15	2·338	2·869	2·326	2·854	2·313	2·839	2·301	2·824	2·290	2·810	2·278	2·795	2·255	2·767	2·232	2·740	2·211	2·714	2·190	2·688
16	2·454	3·426	2·441	3·408	2·428	3·390	2·415	3·372	2·403	3·355	2·391	3·338	2·367	3·305	2·343	3·272	2·321	3·241	2·299	3·210
17	2·573	4·056	2·559	4·034	2·545	4·013	2·531	3·992	2·519	3·971	2·507	3·951	2·482	3·912	2·457	3·873	2·433	3·836	2·410	3·800
18	2·678	4·733	2·664	4·708	2·650	4·683	2·636	4·658	2·622	4·635	2·609	4·611	2·584	4·566	2·569	4·541	2·533	4·476	2·509	4·434
19	2·793	5·500	2·778	5·471	2·764	5·442	2·749	5·414	2·735	5·386	2·721	5·359	2·694	5·305	2·668	5·253	2·642	5·202	2·617	5·153
20	2·894	6·314	2·879	6·281	2·863	6·247	2·848	6·215	2·834	6·183	2·819	6·151	2·791	6·090	2·764	6·030	2·737	5·972	2·711	5·915
21	2·999	7·213	2·983	7·175	2·967	7·137	2·952	7·100	2·937	7·064	2·922	7·028	2·893	6·958	2·864	6·890	2·837	6·823	2·810	6·759
22	3·102	8·189	3·086	8·146	3·069	8·103	3·054	8·061	3·038	8·020	3·022	7·979	2·992	7·899	2·963	7·822	2·934	7·747	2·906	7·673
23	3·203	9·244	3·187	9·195	3·170	9·147	3·153	9·099	3·137	9·053	3·121	9·007	3·090	8·917	3·060	8·829	3·030	8·744	3·002	8·661
24	3·303	10·37	3·286	10·32	3·269	10·27	3·252	10·21	3·235	10·16	3·219	10·11	3·187	10·01	3·155	9·914	3·125	9·818	3·095	9·725
26	3·499	12·90	3·480	12·83	3·462	12·76	3·444	12·70	3·427	12·63	3·409	12·57	3·375	12·44	3·342	12·32	3·310	12·20	3·279	12·09
27	3·595	14·29	3·576	14·21	3·557	14·14	3·538	14·07	3·520	13·99	3·503	13·92	3·468	13·79	3·434	13·65	3·401	13·52	3·368	13·39

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

SINE OF INCLINATION. (1 over:—)

Diameter in Inches.	475		480		485		490		495		500	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
30	3·874	19·01	3·854	18·91	3·833	18·82	3·814	18·72	3·795	18·63	3·775	18·53
33	4·143	24·61	4·121	24·48	4·100	24·35	4·078	24·22	4·058	24·10	4·037	23·98
36	4·403	31·12	4·380	30·96	4·357	30·79	4·334	30·63	4·312	30·48	4·290	30·32
39	4·654	38·61	4·630	38·41	4·605	38·20	4·582	38·01	4·558	37·81	4·535	37·62
42	4·898	47·13	4·872	46·88	4·847	46·63	4·822	46·39	4·797	46·15	4·773	45·92
45	5·135	56·72	5·108	56·42	5·081	56·12	5·055	55·83	5·030	55·55	5·004	55·27
48	5·363	67·43	5·338	67·08	5·310	66·73	5·282	66·38	5·245	65·91	5·229	65·71
51	5·591	79·32	5·562	78·90	5·532	78·49	5·504	78·08	5·476	77·69	5·448	77·29
54	5·811	92·42	5·780	91·93	5·750	91·45	5·720	90·98	5·691	90·52	5·662	90·06
57	6·025	105·7	5·994	106·2	5·962	105·6	5·932	105·1	5·902	104·5	5·872	104·0
60	6·235	122·4	6·203	121·8	6·170	121·1	6·138	120·5	6·107	119·9	6·076	119·3
63	6·441	139·4	6·407	138·7	6·374	137·9	6·341	137·2	6·309	136·5	6·277	135·8
66	6·643	157·8	6·608	157·0	6·573	156·1	6·540	155·3	6·506	154·5	6·474	153·8
69	6·841	177·6	6·805	176·7	6·769	175·7	6·734	174·8	6·700	174·4	6·666	173·1
72	7·035	198·9	6·998	197·8	6·961	196·8	6·926	195·8	6·891	194·8	6·856	193·8
78	7·413	246·0	7·374	244·7	7·336	233·4	7·298	242·1	7·261	240·9	7·225	239·7
84	7·779	299·4	7·739	297·8	7·698	296·2	7·659	294·7	7·620	293·2	7·583	291·8
90	8·135	359·4	8·092	357·5	8·050	355·6	8·008	353·7	7·963	352·0	7·928	350·2
96	8·479	426·2	8·435	424·0	8·391	421·8	8·348	419·6	8·306	417·5	8·264	415·4
102	8·815	500·2	8·769	497·6	8·723	495·0	8·678	492·4	8·634	489·9	8·591	487·5
108	9·142	581·5	9·094	578·5	9·047	575·5	9·000	572·6	8·955	569·7	8·910	566·8
114							9·314	660·3	9·267	656·9	9·221	653·6
120												

Diameter in Inches.	510		520		530		540	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.
30	3·737	18·34	3·701	18·16	3·665	17·99	3·630	17·82
33	3·997	23·74	3·958	23·51	3·920	23·28	3·883	23·05
36	4·247	30·02	4·206	29·73	4·166	29·44	4·126	29·17
39	4·490	37·25	4·446	36·89	4·404	36·53	4·362	36·19
42	4·726	45·46	4·679	45·02	4·635	44·59	4·590	44·16
45	4·954	54·72	4·906	54·19	4·859	53·67	4·813	53·16
48	5·177	65·06	5·127	64·42	5·078	63·81	5·030	63·21
51	5·394	76·53	5·342	75·78	5·291	75·06	5·241	74·35
54	5·606	89·17	5·552	88·30	5·499	87·45	5·447	86·63
57	5·814	103·0	5·757	102·0	5·702	101·0	5·648	100·1
60	6·016	118·1	5·958	116·9	5·901	115·8	5·845	114·7
63	6·215	134·5	6·154	133·2	6·096	131·9	6·038	130·7
66	6·410	152·2	6·347	150·8	6·287	149·3	6·228	147·9
69	6·599	171·3	6·536	169·7	6·474	168·1	6·413	166·5
72	6·788	191·9	6·722	190·0	6·658	188·2	6·595	186·4
78	7·153	237·3	7·084	235·0	7·016	232·8	6·950	230·6
84	7·507	288·9	7·434	285·1	7·363	283·3	7·294	280·7
90	7·850	346·8	7·773	343·4	7·699	340·1	7·627	336·9
96	8·182	411·3	8·103	407·3	8·026	403·4	7·951	399·6
102	8·506	482·7	8·424	478·0	8·344	473·4	8·265	469·0
108	8·822	561·2	8·736	555·8	8·635	550·5	8·570	545·2
114	9·130	647·1	9·041	640·8	8·955	634·8	8·871	628·8
120					9·250	726·5	9·162	719·7

SINE OF INCLINATION. (1 over:—)

Diameter in Inches.	550		560		570		580		590	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
4	·7627	·0665	·7557	·0659						
5	·9167	·1249	·9082	·1238	·8999	·1227	·8919	·1216	·8841	·1205
6	1·063	·2087	1·053	·2068	1·043	·2049	1·034	·2031	1·025	·2013
[illegible]	[illegible]	[illegible]	[illegible]	·3185	1·181	·3156	1·170	·3128	1·160	·3101
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Diameter in Inches.	600		610		620		630		640	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
4										
5	·8765	·1195	·8691	·1185	·8618	·1175	·8547	·1165	·8477	·1156
6	1·016	·1996	1·008	·1979	·9995	·1962	·9913	·1946	·9832	·1930
[illegible]	1·150	·3074	1·140	·3048	1·131	·3023	1·121	·2998	1·112	·2974
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·237	·4319

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	SINE OF INCLINATION. (1 over :—)																			
	550		560		570		580		590		600		610		620		630		640	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
9	1·467	·6481	1·453	·6422	1·440	·6364	1·427	·6308	1·415	·6253	1·403	·6199	1·391	·6147	1·379	·6096	1·368	·6046	1·357	·5997
10	1·592	·8686	1·578	·8607	1·563	·8529	1·550	·8453	1·535	·8380	1·523	·8308	1·510	·8238	1·498	·8169	1·485	·8103	1·473	·8037
11	1·714	1·131	1·698	1·121	1·683	1·111	1·668	1·101	1·654	1·091	1·639	1·082	1·626	1·073	1·612	1·064	1·599	1·055	1·586	1·047
12	1·832	1·439	1·816	1·425	1·799	1·413	1·783	1·401	1·768	1·388	1·753	1·376	1·738	1·365	1·724	1·354	1·709	1·343	1·696	1·332
13	1·948	1·795	1·930	1·779	1·912	1·763	1·896	1·747	1·879	1·732	1·863	1·717	1·847	1·703	1·832	1·689	1·817	1·675	1·802	1·661
14	2·060	2·197	2·041	2·177	2·023	2·158	2·005	2·139	1·988	2·120	1·971	2·102	1·954	2·084	1·938	2·067	1·922	2·050	1·907	2·034
15	2·170	2·663	2·150	2·639	2·131	2·615	2·112	2·592	2·094	2·569	2·076	2·547	2·058	2·526	2·041	2·505	2·025	2·485	2·008	2·465
16	2·277	3·180	2·257	3·151	2·236	3·123	2·217	3·095	2·197	3·068	2·179	3·042	2·160	3·016	2·142	2·992	2·125	2·967	2·108	2·943
17	2·388	3·764	2·366	3·730	2·345	3·697	2·324	3·664	2·304	3·632	2·285	3·601	2·265	3·571	2·247	3·542	2·228	3·513	2·210	3·484
18	2·486	4·393	2·463	4·353	2·441	4·314	2·419	4·276	2·398	4·239	2·378	4·203	2·358	4·167	2·339	4·133	2·320	4·099	2·301	4·066
19	2·593	5·105	2·569	5·059	2·546	5·014	2·524	4·969	2·502	4·926	2·481	4·884	2·460	4·843	2·439	4·803	2·420	4·764	2·400	4·726
20	2·686	5·861	2·662	5·807	2·638	5·755	2·615	5·705	2·592	5·655	2·570	5·607	2·548	5·560	2·527	5·514	2·507	5·469	2·487	5·426
21	2·784	6·696	2·758	6·635	2·734	6·576	2·710	6·518	2·686	6·461	2·663	6·405	2·641	6·353	2·619	6·300	2·598	6·249	2·577	6·199
22	2·880	7·602	2·853	7·533	2·828	7·466	2·803	7·400	2·779	7·336	2·755	7·274	2·732	7·213	2·709	7·153	2·688	7·095	2·666	7·038
23	2·974	8·581	2·947	8·503	2·921	8·427	2·895	8·353	2·870	8·280	2·845	8·211	2·822	8·142	2·798	8·075	2·776	8·009	2·753	7·945
24	3·067	9·636	3·039	9·548	3·012	9·463	2·985	9·380	2·959	9·298	2·934	9·219	2·910	9·142	2·886	9·067	2·862	8·994	2·839	8·921
26	3·249	11·97	3·219	11·87	3·190	11·76	3·162	11·66	3·135	11·56	3·108	11·46	3·082	11·36	3·057	11·27	3·032	11·18	3·008	11·09
27	3·337	13·27	3·307	13·15	3·278	13·03	3·249	12·91	3·221	12·80	3·193	12·69	3·167	12·59	3·141	12·48	3·115	12·38	3·090	12·28
30	3·597	17·65	3·564	17·49	3·533	17·34	3·502	17·19	3·471	17·04	3·442	16·89	3·413	16·75	3·385	16·61	3·358	16·48	3·331	16·35
33	3·847	22·85	3·812	22·64	3·778	22·44	3·745	22·24	3·713	22·05	3·681	21·86	3·650	21·68	3·621	21·50	3·591	21·33	3·563	21·16
36	4·088	28·90	4·051	28·64	4·015	28·38	3·980	28·13	3·946	27·89	3·912	27·65	3·880	27·42	3·848	27·20	3·817	26·98	3·786	26·76
39	4·322	35·85	4·283	35·53	4·245	35·21	4·208	34·90	4·171	34·60	4·136	34·31	4·102	34·03	4·068	33·75	4·035	33·47	4·003	33·21
42	4·549	43·76	4·508	43·37	4·467	42·98	4·428	42·61	4·390	42·24	4·353	41·88	4·317	41·53	4·282	41·19	4·247	40·86	4·213	40·54
45	4·769	52·67	4·726	52·20	4·684	51·73	4·643	51·28	4·603	50·84	4·564	50·41	4·526	49·99	4·489	49·58	4·453	49·18	4·417	48·79
48	4·984	62·63	4·939	62·06	4·895	61·51	4·852	60·97	4·810	60·45	4·770	59·94	4·730	59·44	4·691	58·95	4·653	58·48	4·616	58·01
51	5·193	73·67	5·146	73·00	5·100	72·35	5·056	71·72	5·012	71·10	4·970	70·51	4·929	69·92	4·888	69·35	4·849	68·79	4·810	68·24
54	5·397	85·84	5·348	85·06	5·301	84·31	5·254	83·57	5·209	82·85	5·165	82·15	5·122	81·47	5·081	80·81	5·040	80·16	5·000	79·52
57	5·597	99·18	5·546	98·28	5·497	97·41	5·449	96·56	5·402	95·73	5·357	94·92	5·312	94·14	5·269	93·37	5·226	92·62	5·185	91·88
60	5·792	113·7	5·740	112·7	5·689	111·7	5·639	110·7	5·591	109·7	5·544	108·8	5·498	107·9	5·453	107·0	5·409	106·2	5·366	105·3
63	5·983	129·5	5·929	128·3	5·876	127·2	5·825	126·1	5·775	125·0	5·727	123·9	5·679	122·9	5·633	121·9	5·588	120·9	5·543	120·0
66	6·171	146·6	6·115	145·2	6·061	144·0	6·008	142·7	5·956	141·5	5·906	140·3	5·857	139·1	5·810	138·0	5·763	136·9	5·717	135·8

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS. PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	550		560		570		580		590		600		610		620		630		640	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
69	6·355	165·0	6·297	163·5	6·241	162·0	6·187	160·6	6·134	159·2	6·082	157·9	6·032	156·6	5·983	155·3	5·935	154·1	5·888	152·9
72	6·535	184·7	6·476	183·1	6·419	181·5	6·363	179·9	6·308	178·3	6·255	176·8	6·204	175·4	6·153	173·9	6·104	172·5	6·055	171·2
78	6·887	228·5	6·825	226·4	6·764	224·4	6·706	222·5	6·648	220·6	6·592	218·7	6·538	216·9	6·484	215·1	6·432	213·4	6·381	211·7
84	7·227	278·1	7·162	275·6	7·099	273·2	7·037	270·8	6·977	268·5	6·918	266·2	6·861	264·0	6·805	261·9	6·751	259·8	6·697	257·7
90	7·558	333·9	7·490	330·9	7·423	327·9	7·359	325·1	7·296	322·3	7·235	319·6	7·175	316·9	7·116	314·4	7·059	311·9	7·003	309·4
96	7·878	396·0	7·807	392·4	7·738	388·9	7·671	385·6	7·605	382·3	7·541	379·1	7·479	375·9	7·418	372·9	7·359	369·9	7·301	367·0
102	8·190	464·7	8·116	460·5	8·045	456·5	7·975	452·5	7·907	448·6	7·840	444·9	7·776	441·2	7·712	437·6	7·651	434·1	7·590	430·7
108	8·494	540·3	8·418	535·5	8·343	530·8	8·271	526·2	8·200	521·7	8·131	517·3	8·064	513·0	7·999	508·8	7·935	504·8	7·872	500·8
114	8·791	623·1	8·712	617·5	8·635	612·0	8·560	606·7	8·487	601·5	8·416	596·5	8·346	591·6	8·278	586·8	8·212	582·1	8·147	577·5
120	9·080	713·2	8·999	706·8	8·919	700·5	8·841	694·5	8·767	688·5	8·693	682·8	8·621	677·1	8·552	671·6	8·483	666·3	8·416	661·0

Diameter in Inches.	Sine of Inclination. (1 over :—)																			
	650		660		670		680		690		700		710		720		730		740	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
5	·8410	·1146	·8344	·1137	·8279	·1129	·8216	·1120	·8154	·1111	·8094	·1103	·8034	·1095	·7977	·1087	·7920	·1079	·7864	·1072
6	·9754	·1915	·9678	·1900	·9603	·1885	·9530	·1871	·9458	·1857	·9388	·1843	·9319	·1830	·9252	·1816	·9187	·1803	·9122	·1791
7	1·104	·2950	1·095	·2927	1·086	·2904	1·078	·2882	1·070	·2861	1·062	·2839	1·054	·2819	1·047	·2798	1·039	·2779	1·032	·2759
8	1·227	·4284	1·217	·4251	1·208	·4218	1·199	·4186	1·190	·4155	1·181	·4124	1·172	·4094	1·164	·4065	1·156	·4036	1·148	·4007
9	1·346	·5949	1·336	·5903	1·325	·5857	1·315	·5813	1·306	·5769	1·296	·5727	1·287	·5685	1·277	·5644	1·268	·5604	1·259	·5565
10	1·462	·7974	1·450	·7912	1·439	·7851	1·428	·7791	1·417	·7733	1·407	·7676	1·397	·7620	1·387	·7566	1·377	·7512	1·367	·7460
11	1·574	1·038	1·561	1·030	1·549	1·022	1·538	1·015	1·526	1·007	1·515	1·000	1·504	·9927	1·493	·9856	1·483	·9786	1·472	·9718
12	1·682	1·321	1·669	1·311	1·656	1·301	1·644	1·291	1·632	1·281	1·620	1·272	1·608	1·263	1·596	1·254	1·585	1·245	1·574	1·236
13	1·788	1·648	1·774	1·635	1·761	1·623	1·747	1·611	1·734	1·599	1·722	1·587	1·709	1·575	1·697	1·564	1·685	1·553	1·673	1·542
14	1·892	2·018	1·877	2·002	1·863	1·986	1·848	1·971	1·835	1·957	1·821	1·942	1·808	1·928	1·795	1·915	1·782	1·901	1·770	1·888
15	1·993	2·445	1·977	2·426	1·962	2·408	1·947	2·390	1·933	2·372	1·918	2·354	1·905	2·337	1·891	2·321	1·878	2·303	1·865	2·288
16	2·091	2·920	2·075	2·898	2·059	2·875	2·044	2·854	2·028	2·832	2·014	2·812	1·999	2·791	1·985	2·771	1·971	2·752	1·957	2·733
17	2·193	3·457	2·176	3·430	2·159	3·404	2·143	3·378	2·127	3·353	2·112	3·329	2·096	3·305	2·081	3·281	2·067	3·258	2·052	3·235
18	2·283	4·034	2·265	4·003	2·248	3·973	2·231	3·943	2·214	3·913	2·198	3·885	2·182	3·857	2·167	3·829	2·151	3·802	2·137	3·776
19	2·381	4·689	2·363	4·653	2·345	4·617	2·327	4·582	2·310	4·548	2·293	4·515	2·276	4·483	2·260	4·451	2·244	4·419	2·229	4·389
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2·376	5·183	2·358	5·146	2·342	5·109	2·325	5·074	2·309	5·038

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	650		660		670		680		690		700		710		720		730		740	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
21	2·557	6·151	2·537	6·103	2·518	6·056	2·499	6·011	2·480	5·966	2·462	5·923	2·444	5·880	2·427	5·838	2·410	5·797	2·393	5·757
22	2·645	6·983	2·625	6·929	2·605	6·876	2·585	6·825	2·566	6·774	2·547	6·724	2·529	6·676	2·511	6·629	2·493	6·582	2·476	6·537
23	2·732	7·883	2·711	7·822	2·690	7·762	2·670	7·704	2·650	7·647	2·631	7·591	2·612	7·536	2·593	7·483	2·575	7·430	2·557	7·379
24	2·817	8·852	2·796	8·783	2·774	8·716	2·753	8·651	2·733	8·587	2·713	8·524	2·693	8·463	2·674	8·403	2·656	8·344	2·637	8·286
26	2·984	11·00	2·961	10·92	2·939	10·83	2·917	10·75	2·895	10·67	2·874	10·59	2·853	10·52	2·833	10·44	2·813	10·37	2·794	10·30
27	3·066	12·19	3·042	12·09	3·019	12·00	2·997	11·91	2·974	11·82	2·953	11·74	2·932	11·65	2·911	11·57	2·890	11·49	2·870	11·41
30	3·305	16·22	3·279	16·10	3·254	15·97	3·230	15·85	3·206	15·74	3·183	15·62	3·160	15·51	3·138	15·40	3·116	15·29	3·094	15·19
33	3·535	20·99	3·508	20·83	3·481	20·67	3·455	20·52	3·429	20·37	3·404	20·22	3·380	20·07	3·356	19·93	3·333	19·79	3·310	19·66
36	3·757	26·55	3·728	26·35	3·700	26·15	3·672	25·95	3·645	25·76	3·618	25·58	3·592	25·39	3·567	25·21	3·542	25·04	3·518	24·87
39	3·972	32·95	3·941	32·70	3·911	32·45	3·882	32·20	3·854	31·97	3·826	31·74	3·798	31·51	3·771	31·29	3·745	31·07	3·719	30·85
42	4·180	40·22	4·148	39·91	4·117	39·61	4·086	39·31	4·056	39 02	4·027	38·74	3·998	38·46	3·970	38·19	3·942	37·93	3·915	37·67
45	4·383	48·41	4·350	48·04	4·317	47·67	4·284	47·32	4·253	46·97	4·222	46·63	4·192	46·30	4·162	45·97	4·133	45·65	4·105	45·34
48	4·581	57·56	4·545	57·12	4·511	56·69	4·477	56·26	4·444	55·85	4·412	55·45	4·381	55·05	4·350	54·66	4·320	54·28	4·290	53·91
51	4·773	67·71	4·736	67·19	4·701	66·68	4·665	66·19	4·631	65·70	4·598	65·23	4·565	64·76	4·533	64·30	4·501	63·86	4·470	63·42
54	4·961	78·90	4·923	78·30	4·886	77·70	4·849	77·13	4·814	76·56	4·779	76·00	4·745	75·46	4·711	74·93	4·679	74·41	4·647	73·90
57	5·145	91·17	5·105	90·47	5·067	89·78	5·029	89·12	4·992	88·46	4·956	87·82	4·920	87·20	4·886	86·58	4·852	85·98	4·819	85·39
60	5·324	104·5	5·284	103·7	5·244	102·9	5·205	102·2	5·166	101·4	5·129	100·7	5·092	99·99	5·057	99·29	5·022	98·60	4·987	97·93
63	5·500	119·0	5·458	118·1	5·417	117·2	5·377	116·4	5·337	115·5	5·299	114·7	5·261	113·8	5·224	113·1	5·188	112·3	5·152	111·5
66	5·673	134·7	5·629	133·7	5·587	132·7	5·545	131·7	5·505	130·7	5·465	129·8	5·426	128·9	5·388	128·0	5·351	127·1	5·314	126·2
69	5·842	151·7	5·797	150·5	5·754	149·4	5·711	148·3	5·669	147·2	5·628	146·1	5·588	145·1	5·549	144·1	5·510	143·1	5·473	142·1
72	6·008	169·8	5·962	168·6	5·917	167·3	5·873	166·0	5·830	164·8	5·788	163·6	5·747	162·5	5·707	161·3	5·667	160·2	5·629	159·1
78	6·332	210·1	6·284	208·5	6·236	203·9	6·190	205·4	6·145	203·9	6·100	202·4	6 057	201 0	6·015	199·6	5·973	198·2	5·932	196·8
84	6·645	255·7	6·595	253·8	6·545	251·9	6·496	250·0	6·449	248·2	6·402	246·4	6·357	244·6	6·312	242·9	6·269	241·2	6·226	239·6
90	6·949	307·0	6·896	304·6	6·844	302·4	6·794	300·1	6·744	297·9	6·695	295·8	6·648	293·7	6·601	291·6	6·556	289·6	6·511	287·6
96	7·244	364·1	7·189	361·3	7·135	358·6	7·082	356·0	7·030	353·4	6·980	350·8	6·930	348·3	6·882	345·9	6·834	343·5	6·788	341·2
102	7·532	427·4	7·474	424·1	7·418	420·9	7·363	417·8	7·309	414·7	7·256	411·7	7·205	408·8	7·155	406·0	7·105	403·2	7·057	400·4
108	7·811	496·9	7·752	493·1	7·694	489·4	7·637	485·8	7·581	482·3	7·526	478·8	7·473	475·4	7·421	472·1	7·370	468·8	7·320	465·6
114	8·085	573·0	8·023	568·7	7·963	564·4	7·904	560·2	7·846	556·1	7·790	552·1	7·734	548·2	7·681	544·4	7·628	540·6	7·576	537·0
120	8·351	655·9	8·288	650·9	8·225	646·0	8·165	641·2	8·105	636·6	8·047	632·0	7·990	627·5	7·934	623·1	7·880	618·8	7·826	614·6

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

SINE OF INCLINATION. (1 over:—)

Diameter in Inches.	750 V.	750 Q.	760 V.	760 Q.	770 V.	770 Q.	780 V.	780 Q.	790 V.	790 Q.
5	·7809	·1064	·7756	·1057	·8936	·1754	·8877	·1743	·8818	·1731
6	·9059	·1778	·8997	·1766	1·011	·2703	1·004	·2685	·9981	·2667
7	1·025	·2740	1·018	·2721	1·124	·3926	1·117	·3900	1·110	·3874
8	1·140	·3980	1·132	·3953	1·234	·5452	1·226	·5416	1·218	·5381
9	1·251	·5527	1·242	·5489	1·340	·7308	1·331	·7260	1·322	·7212
10	1·358	·7408	1·349	·7358	1·442	·9521	1·433	·9458	1·423	·9396
11	1·462	·9651	1·452	·9586	1·542	1·211	1·532	1·203	1·522	1·195
12	1·563	1·228	1·553	1·219	1·639	1·511	1·629	1·501	1·618	1·491
13	1·662	1·532	1·651	1·521	1·734	1·850	1·723	1·838	1·712	1·826
14	1·758	1·875	1·746	1·862	1·827	2·242	1·815	2·227	1·803	2·213
15	1·852	2·273	1·839	2·257	1·918	2·678	1·905	2·660	1·893	2·643
16	1·944	2·714	1·931	2·696	2·011	3·170	1·998	3·149	1·985	3·129
17	2·038	3·213	2·025	3·192	2·094	3·700	2·080	3·676	2·065	3·652
18	2·122	3·750	2·108	3·725	2·184	4·301	2·170	4·272	2·155	4·244
19	2·214	4·359	2·199	4·330	2·263	4·937	2·248	4·905	2·233	4·873
20	2·293	5·004	2·278	4·970	2·345	5·641	2·330	5·604	2·315	5·568
21	2·377	5·718	2·361	5·679	2·426	6·405	2·410	6·363	2·395	6·322
22	2·459	6·492	2·443	6·448	2·506	7·231	2·489	7·183	2·473	7·137
23	2·540	7·329	2·523	7·280	2·584	8·120	2·567	8·067	2·551	8·014
24	2·619	8·230	2·602	8·175	2·738	10·09	2·720	10·03	2·702	9·964
26	2·775	10·23	2·756	10·16	2·813	11·18	2·795	11·11	2·776	11·04
27	2·851	11·33	2·832	11·26	3·032	14·88	3·012	14·79	2·993	14·69
30	3·073	15·08	3·053	14·98	3·244	19·26	3·222	19·14	3·201	19·01
33	3·287	19·52	3·265	19·39	3·448	24·37	3·425	24·21	3·403	24·05
36	3·494	24·70	3·471	24·53	3·645	30·24	3·621	30·04	3·598	29·85
39	3·694	30·64	3·670	30·44	3·837	36·91	3·812	36·67	3·787	36·44
42	3·888	37·41	3·862	37·16	4·023	44·43	3·997	44·15	3·971	43·86
45	4·077	45·03	4·050	44·73	4·205	52·84	4·177	52·49	4·150	52·15
48	4·261	53·54	4·233	53·19	4·381	62·16	4·353	61·75	4·325	61·36
51	4·440	62·99	4·411	62·57	[illegible]	[illegible]	[illegible]	71·96	4·495	71·50

Diameter in Inches.	800 V.	800 Q.	810 V.	810 Q.	820 V.	820 Q.	830 V.	830 Q.	840 V.	840 Q.
5	·8761	·1720	·8704	·1709	·8649	·1698	·8594	·1687	·8541	·1677
6	·9917	·2650	·9853	·2633	·9791	·2616	·9729	·2600	·9669	·2584
7	1·102	·3849	1·095	·3824	1·088	·3800	1·082	·3776	1·075	·3752
8	1·210	·5346	1·202	·5311	1·194	·5278	1·187	·5245	1·180	·5212
9	1·313	·7166	1·305	·7120	1·297	·7075	1·289	·7031	1·281	·6987
10	1·414	·9336	1·405	·9276	1·396	·9218	1·388	·9160	1·379	·9103
11	1·512	1·188	1·502	1·180	1·493	1·173	1·484	1·165	1·475	1·158
12	1·607	1·482	1·597	1·472	1·587	1·463	1·577	1·454	1·568	1·445
13	1·701	1·814	1·690	1·802	1·679	1·791	1·669	1·780	1·658	1·769
14	1·791	2·198	1·780	2·184	1·769	2·171	1·758	2·157	1·747	2·144
15	1·880	2·626	1·868	2·609	1·857	2·593	1·845	2·576	1·834	2·561
16	1·972	3·109	1·960	3·089	1·947	3·070	1·935	3·051	1·923	3·032
17	2·053	3·628	2·040	3·605	2·027	3·583	2·014	3·560	2·002	3·538
18	2·142	4·217	2·128	4·190	2·115	4·164	2·102	4·138	2·089	4·113
19	2·219	4·841	2·205	4·811	2·191	4·781	2·177	4·751	2·164	4·722
20	2·300	5·532	2·285	5·497	2·271	5·463	2·257	5·429	2·243	5·396
21	2·379	6·281	2·364	6·242	2·349	6·203	2·335	6·164	2·321	6·127
22	2·457	7·091	2·442	7·046	2·427	7·002	2·412	6·959	2·397	6·916
23	2·534	7·963	2·518	7·912	2·503	7·863	2·487	7·814	2·472	7·767
24	2·685	9·901	2·668	9·838	2·651	9·777	2·635	9·716	2·619	9·657
26	2·759	10·97	2·741	10·90	2·724	10·83	2·707	10·76	2·691	10·70
27	2·974	14·60	2·955	14·50	2·937	14·41	2·919	14·32	2·901	14·24
30	3·181	18·89	3·161	18·77	3·141	18·66	3·122	18·54	3·103	18·43
33	3·381	23·90	3·360	23·75	3·339	23·60	3·319	23·46	3·298	23·31
36	3·575	29·66	3·553	29·47	3·531	29·29	3·509	29·11	3·488	28·93
39	3·763	36·21	3·739	35·98	3·716	35·76	3·693	35·53	3·671	35·32
42	3·946	43·58	3·921	43·31	3·897	43·04	3·873	42·78	3·850	42·52
45	4·124	51·82	4·098	51·50	4·073	51·18	4·048	50·87	4·023	50·56
48	4·297	60·97	4·271	60·58	4·244	60·21	4·218	59·84	4·193	59·48
51	4·467	71·05	4·439	70·60	4·412	70·17	4·384	69·73	4·358	69·31

TABLE [illegible] (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—) 750		760		770		780		790		800		810		820		830		840	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
57	4·786	84·82	4·754	84·25	4·723	83·70	4·692	83·15	4·662	82·62	4·633	82·09	4·604	81·58	4·575	81·08	4·547	80·58	4·520	80·10
60	4·954	97·27	4·921	96·62	4·888	95·98	4·856	95·36	4·825	94·75	4·795	94·15	4·765	93·56	4·735	92·98	4·706	92·41	4·678	91·85
63	5·117	110·7	5·084	110·0	5·050	109·3	5·017	108·6	4·985	107·9	4·953	107·2	4·922	106·5	4·892	105·9	4·862	105·2	4·833	104·6
66	5·278	125·4	5·243	124·5	5·209	123·7	5·175	122·9	5·142	122·1	5·109	121·3	5·077	120·6	5·046	119·8	5·015	119·1	4·985	118·4
69	5·436	141·1	5·400	140·2	5·364	139·3	5·329	138·4	5·295	137·5	5·262	136·6	5·229	135·7	5·197	134·9	5·165	134·1	5·134	133·3
72	5·591	158·0	5·554	157·0	5·517	156·0	5·481	154·9	5·446	154·0	5·412	153·0	5·378	152·0	5·345	151·1	5·312	150·2	5·280	149·3
78	5·892	195·5	5·853	194·2	5·815	192·9	5·777	191·7	5·740	190·4	5·704	189·2	5·668	188·1	5·633	186·9	5·599	185·8	5·565	184·6
84	6·184	238·0	6·143	236·4	6·103	234·8	6·063	233·3	6·025	231·8	5·987	230·4	5·949	228·9	5·913	227·5	5·877	226·1	5·841	224·8
90	6·467	285·7	6·425	283·8	6·382	281·9	6·341	280·1	6·300	278·3	6·261	276·6	6·222	274·8	6·184	273·2	6·146	271·5	6·109	269·9
96	6·742	338·9	6·698	336·6	6·654	334·4	6·611	332·3	6·568	330·8	6·527	328·1	6·486	326·0	6·447	324·0	6·407	322·0	6·369	320·1
102	7·010	397·7	6·964	395·1	6·918	392·5	6·873	390·0	6·829	387·5	6·786	385·1	6·744	382·7	6·703	380·3	6·662	378·0	6·622	375·7
108	7·270	462·5	7·223	459·5	7·175	456·4	7·129	453·5	7·083	450·6	7·039	447·8	6·995	445·0	6·952	442·3	6·910	439·6	6·868	436·9
114	7·525	533·4	7·475	529·9	7·426	526·4	7·378	523·0	7·331	519·6	7·285	516·4	7·240	513·2	7·196	510·0	7·152	506·9	7·109	503·9
120	7·773	610·5	7·722	606·5	7·672	602·5	7·622	598·6	7·573	594·8	7·526	591·1	7·479	587·4	7·433	583·8	7·388	580·3	7·344	576·8

Diameter in Inches.	Sine of Inclination. (1 over:—) 850		860		870		880		890		900		910		920		930		940	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
6	·8489	·1666	·8437	·1656	·8386	·1646	·8337	·1637	·8288	·1627	·8240	·1617	·8182	·1606	·8146	·1599	·8099	·1590	·8055	·1581
7	·9609	·2568	·9550	·2552	·9494	·2537	·9438	·2522	·9382	·2507	·9328	·2493	·9275	·2478	·9222	·2464	·9170	·2450	·9119	·2437
8	1·068	·3730	1·062	·3707	1·055	·3685	1·049	·3664	1·043	·3642	1·037	·3631	1·031	·3600	1·025	·3580	1·019	·3560	1·014	·3540
9	1·172	·5181	1·165	·5149	1·158	·5119	1·151	·5088	1·145	·5059	1·138	·5029	1·132	·5001	1·125	·4972	1·119	·4944	1·113	·4917
10	1·273	·6945	1·265	·6902	1·258	·6861	1·250	·6821	1·243	·6781	1·236	·6742	1·229	·6704	1·222	·6666	1·215	·6628	1·208	·6592
11	1·371	·9048	1·362	·8993	1·354	·8940	1·346	·8887	1·338	·8835	1·331	·8785	1·323	·8735	1·316	·8685	1·308	·8637	1·301	·8589
12	1·466	1·151	1·457	1·144	1·448	1·137	1·440	1·131	1·431	1·124	1·423	1·117	1·415	1·111	1·407	1·105	1·399	1·099	1·391	1·093
13	1·558	1·436	1·549	1·427	1·539	1·419	1·530	1·411	1·522	1·402	1·513	1·394	1·504	1·386	1·496	1·379	1·487	1·371	1·479	1·363
14	1·648	1·758	1·638	1·747	1·629	1·737	1·619	1·727	1·610	1·717	1·600	1·707	1·591	1·697	1·582	1·688	1·574	1·678	1·565	1·669
15	1·737	2·131	1·726	2·118	1·716	2·106	1·706	2·093	1·696	2·081	1·686	2·069	1·677	2·058	1·667	2·046	1·658	2·035	1·649	2·023
16	1·823	2·545	1·812	2·530	1·801	2·515	1·791	2·500	1·780	2·486	1·770	2·471	1·760	2·457	1·750	2·444	1·740	2·430	1·731	2·417
17	1·912	3·014	1·900	2·995	1·889	2·978	1·878	2·960	1·867	2·943	1·856	2·926	1·846	2·910	1·835	2·893	1·825	2·877	1·815	2·861
18	1·990	3·517	1·978	3·496	1·966	3·475	1·955	3·455	1·944	3·435	1·932	3·415	1·922	3·396	1·911	3·377	1·900	3·358	1·890	3·340
19	2·076	4·088	2·063	4·063	2·051	4·040	2·039	4·016	2·028	3·993	2·016	3·970	2·005	3·947	1·993	3·925	1·982	3·904	1·971	3·882

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	850		860		870		880		890		900		910		920		930		940	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
20	2·151	4·693	2·138	4·665	2·126	4·468	2·113	4·611	2·101	4·584	2·089	4·558	2·077	4·532	2·065	4·507	2·054	4·482	2·043	4·457
21	2·229	5·363	2·216	5·331	2·203	5·300	2·190	5·269	2·178	5·238	2·165	5·208	2·153	5·179	2·141	5·150	2·129	5·121	2·117	5·093
22	2·307	6·090	2·293	6·053	2·279	6·017	2·266	5·982	2·253	5·948	2·240	5·914	2·227	5·881	2·215	5·848	2·203	5·815	2·191	5·783
23	2·382	6·875	2·368	6·833	2·354	6·793	2·341	6·754	2·327	6·715	2·314	6·676	2·301	6·639	2·288	6·602	2·275	6·565	2·263	6·529
24	2·457	7·720	2·442	7·673	2·428	7·629	2·414	7·584	2·400	7·541	2·386	7·498	2·373	7·455	2·360	7·414	2·346	7·373	2·334	7·332
26	2·603	9·599	2·587	9·541	2·572	9·486	2·557	9·430	2·543	9·376	2·528	9·323	2·514	9·270	2·500	9·218	2·486	9·167	2·473	9·117
27	2·675	10·63	2·658	10·57	2·643	10·51	2·628	10·44	2·613	10·38	2·598	10·33	2·583	10·27	2·569	10·21	2·554	10·15	2·541	10·10
30	2·883	14·15	2·866	14·07	2·849	13·98	2·833	13·90	2·817	13·82	2·801	13·74	2·785	13·67	2·769	13·59	2·754	13·52	2·739	13·44
33	3·084	18·32	3·066	18·21	3·048	18·10	3·030	18·00	3·013	17·89	2·996	17·79	2·979	17·69	2·963	17·59	2·946	17·50	2·930	17·40
36	3·279	23·17	3·259	23·03	3·240	22·90	3·221	22·77	3·203	22·64	3·185	22·51	3·167	22·38	3·149	22·26	3·132	22·14	3·115	22·02
39	3·467	28·76	3·446	28·59	3·425	28·42	3·406	28·26	3·387	28·09	3·367	27·93	3·349	27·78	3·330	27·62	3·312	27·47	3·294	27·32
42	3·649	35·11	3·627	34·90	3·606	34·70	3·585	34·50	3·565	34·30	3·545	34·10	3·525	33·91	3·505	33·73	3·486	33·54	3·467	33·36
45	3·827	42·26	3·804	42·01	3·782	41·77	3·760	41·53	3·738	41·29	3·717	41·05	3·696	40·83	3·676	40·60	3·655	40·38	3·636	40·16
48	3·999	50·26	3·975	49·96	3·952	49·67	3·930	49·38	3·907	49·10	3·885	48·82	3·863	48·55	3·842	48·28	3·821	48·02	3·800	47·76
51	4·168	59·13	4·143	58·77	4·119	58·43	4·095	58·10	4·072	57·76	4·049	57·44	4·026	57·12	4·004	56·80	3·982	56·49	3·960	56·18
54	4·332	68·90	4·306	68·49	4·281	68·09	4·257	67·70	4·232	67·32	4·208	66·94	4·185	66·56	4·162	66·19	4·139	65·83	4·117	65·48
57	4·493	79·62	4·466	79·14	4·440	78·69	4·415	78·23	4·389	77·79	4·365	77·35	4·340	76·92	4·316	76·49	4·293	76·07	4·270	75·66
60	4·650	91·31	4·622	90·76	4·596	90·24	4·569	89·72	4·543	89·21	4·518	88·71	4·492	88·21	4·468	87·73	4·443	87·25	4·419	86·78
63	4·804	104·0	4·775	103·3	4·748	102·7	4·721	102·2	4·694	101·6	4·667	101·0	4·641	100·4	4·616	99·93	4·591	99·38	4·566	98·84
66	4·955	117·7	4·926	117·0	4·897	116·3	4·869	115·6	4·841	115·0	4·814	114·3	4·787	113·7	4·761	113·1	4·735	112·5	4·710	111·9
69	5·103	132·5	5·073	131·7	5·044	130·9	5·015	130·2	4·986	129·4	4·958	128·7	4·931	128·0	4·904	127·3	4·877	126·6	4·851	125·9
72	5·249	148·4	5·218	147·5	5·188	146·6	5·158	145·8	5·128	145·0	5·100	144·2	5·071	143·4	5·043	142·6	5·016	141·8	4·989	141·0
78	5·532	183·6	5·499	182·5	5·468	181·4	5·436	180·4	5·406	179·3	5·375	178·3	5·345	177·3	5·316	176·4	5·287	175·4	5·259	174·5
84	5·807	223·4	5·772	222·1	5·739	220·8	5·706	219·6	5·674	218·3	5·642	217·1	5·611	215·9	5·580	214·7	5·549	213·5	5·520	212·4
90	6·073	268·3	6·037	266·7	6·002	265·1	5·968	263·6	5·934	262·1	5·901	260·7	5·868	259·2	5·836	257·8	5·804	256·4	5·773	255·0
96	6·331	318·2	6·294	316·3	6·258	314·5	6·222	312·7	6·186	310·9	6·152	309·2	6·118	307·5	6·084	305·8	6·051	304·1	6·019	302·5
102	6·583	373·5	6·544	371·3	6·506	369·2	6·469	367·1	6·432	365·0	6·396	362·9	6·361	360·9	6·326	359·0	6·292	357·0	6·258	355·1
108	6·828	434·3	6·787	431·8	6·748	429·3	6·710	426·8	6·672	424·4	6·635	422·1	6·598	419·7	6·562	417·4	6·526	415·2	6·491	412·9
114	7·067	500·9	7·025	498·0	6·985	495·1	6·945	492·3	6·906	489·5	6·867	486·7	6·829	484·1	6·792	481·4	6·755	478·8	6·719	476·2
120	7·301	573·4	7·257	570·0	7·216	566·7	7·175	563·5	7·134	560·3	7·094	557·2	7·055	554·1	7·017	551·1	6·979	548·1	6·941	545·2

[illegible] DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over :—) 950		960		970		980		990		1000		1050		1100		1150		1200	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
6	·8010	·1572	·7967	·1564	·7923	·1555	·7881	·1547	·7839	·1539										
7	·9069	·2423	·9019	·2410	·8971	·2397	·8923	·2384	·8876	·2372	·8830	·2360	·8607	·2295	·8400	·2245	·8206	·2193	·8024	·2144
8	1·008	·3521	1·003	·3501	·9978	·3483	·9925	·3464	·9872	·3446	·9821	·3428	·9574	·3342	·9344	·3262	·9128	·3186	·8927	·3116
9	1·107	·4890	1·101	·4864	1·095	·4837	1·089	·4812	1·083	·4786	1·078	·4762	1·051	·4642	1·026	·4531	1·002	·4427	·9779	·4329
10	1·202	·6556	1·195	·6520	1·189	·6485	1·182	·6451	1·176	·6417	1·171	·6384	1·141	·6224	1·114	·6075	1·088	·5934	1·064	·5805
11	1·294	·8542	1·287	·8496	1·280	·8450	1·273	·8405	1·267	·8361	1·260	·8318	1·229	·8110	1·200	·7916	1·172	·7734	1·146	·7565
12	1·384	1·087	1·376	1·081	1·369	1·075	1·362	1·069	1·354	1·064	1·348	1·059	1·314	1·032	1·284	1·008	1·253	·9844	1·226	·9628
13	1·471	1·356	1·463	1·349	1·455	1·341	1·448	1·334	1·440	1·327	1·433	1·321	1·397	1·287	1·363	1·257	1·333	1·228	1·304	1·202
14	1·556	1·660	1·548	1·651	1·540	1·642	1·532	1·634	1·524	1·625	1·516	1·617	1·478	1·577	1·443	1·539	1·410	1·504	1·379	1·471
15	1·640	2·012	1·631	2·002	1·622	1·991	1·614	1·980	1·605	1·970	1·597	1·960	1·557	1·911	1·520	1·865	1·486	1·823	1·453	1·784
16	1·721	2·404	1·712	2·391	1·703	2·378	1·694	2·365	1·685	2·353	1·677	2·341	1·635	2·283	1·596	2·229	1·560	2·178	1·526	2·130
17	1·805	2·846	1·796	2·831	1·786	2·816	1·777	2·801	1·767	2·786	1·759	2·772	1·715	2·703	1·675	2·640	1·636	2·579	1·600	2·522
18	1·879	3·322	1·869	3·304	1·859	3·286	1·850	3·269	1·840	3·252	1·831	3·236	1·785	3·155	1·743	3·080	1·703	3·010	1·666	2·944
19	1·961	3·861	1·950	3·840	1·940	3·820	1·930	3·800	1·920	3·780	1·910	3·761	1·863	3·668	1·819	3·580	1·777	3·499	1·739	3·423
20	2·032	4·433	2·021	4·409	2·010	4·386	2·000	4·363	1·989	4·340	1·979	4·318	1·930	4·210	1·884	4·111	1·842	4·019	1·802	3·931
21	2·106	5·066	2·095	5·039	2·083	5·012	2·072	4·986	2·062	4·960	2·053	4·935	2·001	4·812	1·953	4·698	1·909	4·592	1·868	4·492
22	2·179	5·752	2·167	5·721	2·156	5·691	2·144	5·661	2·133	5·632	2·123	5·603	2·075	5·477	2·021	5·335	1·975	5·214	1·932	5·101
23	2·250	6·494	2·238	6·459	2·227	6·425	2·215	6·391	2·203	6·358	2·193	6·326	2·138	6·169	2·088	6·023	2·040	5·887	1·996	5·759
24	2·321	7·293	2·309	7·254	2·296	7·215	2·284	7·178	2·272	7·140	2·262	7·104	2·205	6·928	2·153	6·765	2·105	6·613	2·059	6·469
26	2·459	9·068	2·446	9·020	2·433	8·972	2·420	8·925	2·408	8·879	2·396	8·834	2·336	8·615	2·282	8·412	2·230	8·222	2·182	8·044
27	2·527	10·04	2·513	9·995	2·500	9·942	2·487	9·890	2·474	9·838	2·462	9·788	2·401	9·547	2·345	9·321	2·291	9·111	2·242	8·914
30	2·724	13·37	2·710	13·30	2·695	13·23	2·681	13·16	2·667	13·09	2·655	13·03	2·590	12·71	2·528	12·41	2·470	12·13	2·417	11·87
33	2·914	17·31	2·899	17·22	2·884	17·13	2·869	17·04	2·854	16·95	2·840	16·87	2·770	16·45	2·705	16·06	2·643	15·70	2·587	15·36
36	3·098	21·90	3·082	21·78	3·065	21·67	3·049	21·55	3·034	21·44	3·019	21·34	2·945	20·81	2·875	20·32	2·811	19·87	2·750	19·44
39	3·276	27·18	3·259	27·03	3·241	26·89	3·225	26·75	3·208	26·61	3·192	26·48	3·114	25·83	3·041	25·22	2·972	24·66	2·908	24·13
42	3·449	33·18	3·430	33·00	3·412	32·83	3·395	32·66	3·377	32·49	3·360	32·33	3·278	31·54	3·201	30·80	3·129	30·10	3·062	29·46
45	3·616	39·94	3·597	39·73	3·578	39·52	3·560	39·32	3·541	39·11	3·524	38·92	3·438	37·97	3·357	37·08	3·282	36·25	3·212	35·47
48	3·780	47·50	3·760	47·25	3·740	47·00	3·721	46·76	3·702	46·52	3·683	46·28	3·593	45·15	3·509	44·10	3·431	43·11	3·357	42·19
51	3·939	55·88	3·918	55·59	3·898	55·30	3·878	55·01	3·858	54·73	3·841	54·46	3·745	53·12	3·657	51·88	3·575	50·72	3·499	49·64
54	4·095	65·13	4·073	64·78	4·052	64·44	4·031	64·11	4·010	63·78	3·990	63·46	3·893	61·91	3·802	60·47	3·717	59·15	3·638	57·85
57	4·247	75·26	4·224	74·86	4·202	74·47	4·181	74·09	4·159	73·70	4·138	73·33	4·037	71·55	3·943	69·88	3·855	68·32	3·773	66·86

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—) 950 V.	950 Q.	960 V.	960 Q.	970 V.	970 Q.	980 V.	980 Q.	990 V.	990 Q.	1000 V.	1000 Q.	1050 V.	1050 Q.	1100 V.	1100 Q.	1150 V.	1150 Q.	1200 V.	1200 Q.
60	4·396	86·31	4·373	85·86	4·350	85·41	4·327	84·97	4·305	84·53	4·284	84·11	4·179	82·06	4·082	80·14	3·991	78·36	3·906	76·69
63	4·541	98·32	4·518	97·80	4·494	97·29	4·471	96·78	4·448	96·29	4·426	95·81	4·318	93·47	4·217	91·29	4·124	89·27	4·036	87·36
66	4·684	111·3	4·660	110·7	4·635	110·1	4·611	109·5	4·588	109·0	4·565	108·4	4·453	105·7	4·349	103·4	4·253	101·0	4·163	98·90
69	4·825	125·2	4·799	124·6	4·774	123·9	4·750	123·3	4·725	122·7	4·701	122·1	4·587	119·1	4·481	116·4	4·381	113·8	4·288	111·3
72	4·962	140·3	4·936	139·5	4·910	138·8	4·885	138·1	4·860	137·4	4·836	136·7	4·718	133·4	4·609	130·3	4·506	127·4	4·410	124·7
78	5·231	173·5	5·203	172·6	5·176	171·7	5·149	170·8	5·123	170·0	5·098	169·2	4·974	165·0	4·858	161·2	4·750	157·6	4·649	154·3
84	5·490	211·3	5·462	210·2	5·433	209·1	5·405	208·0	5·377	206·9	5·351	205·9	5·221	200·9	5·100	196·3	4·987	191·9	4·881	187·8
90	5·742	253·7	5·712	252·3	5·682	251·0	5·653	249·7	5·624	248·4	5·596	247·2	5·460	241·2	5·334	235·7	5·216	230·4	5·105	225·5
96	5·987	300·9	5·955	299·3	5·924	297·8	5·894	296·2	5·864	294·7	5·834	293·3	5·693	286·2	5·562	279·6	5·439	273·4	5·323	267·6
102	6·225	353·2	6·192	351·4	6·160	349·5	6·128	347·7	6·097	346·0	6·067	344·3	5·920	335·9	5·783	328·2	5·655	321·0	5·336	314·1
108	6·457	410·8	6·423	408·6	6·390	406·5	6·357	404·4	6·325	402·3	6·293	400·4	6·141	390·7	5·999	381·6	5·866	373·2	5·742	365·3
114	6·683	473·7	6·648	471·2	6·614	468·8	6·580	466·4	6·546	464·0	6·514	461·7	6·356	450·6	6·209	440·2	6·072	430·4	5·944	421·3
120	6·905	542·3	6·868	539·4	6·833	536·6	6·798	533·9	6·763	531·2	6·730	528·6	6·567	515·8	6·415	503·9	6·273	492·7	6·141	482·3

Diameter in Inches.	Sine of Inclination. (1 over:—) 1250 V.	1250 Q.	1300 V.	1300 Q.	1350 V.	1350 Q.	1400 V.	1400 Q.	1450 V.	1450 Q.	1500 V.	1500 Q.	1550 V.	1550 Q.	1600 V.	1600 Q.	1650 V.	1650 Q.	1700 V.	1700 Q.
8	·8758	·3050	·8559	·2987	·8389	·2928	·8229	·2873												
9	·9591	·4237	·9395	·4151	·9210	·4068	·9035	·3991	·8868	·3918	·8711	·3848	·8560	·3782	·8417	·3718	·8280	·3658		
10	1·042	·5681	1·021	·5566	1·000	·5456	·9814	·5353	·9634	·5254	·9463	·5161	·9300	·5072	·9145	·4988	·8996	·4907	·8855	·4829
11	1·122	·7405	1·099	·7254	1·078	·7112	1·057	·6976	1·038	·6848	1·019	·6727	1·002	·6612	·9852	·6503	·9692	·6398	·9540	·6297
12	1·200	·9425	1·176	·9233	1·153	·9052	1·131	·8881	1·110	·8717	1·090	·8565	1·072	·8417	1·054	·8277	1·037	·8143	1·021	·8016
13	1·276	1·176	1·250	1·252	1·225	1·230	1·202	1·108	1·180	1·088	1·160	1·070	1·140	1·051	1·121	1·033	1·103	1·017	1·086	1·006
14	1·350	1·440	1·323	1·411	1·297	1·383	1·273	1·357	1·250	1·333	1·228	1·309	1·206	1·287	1·186	1·265	1·167	1·245	1·149	1·226
15	1·422	1·746	1·394	1·711	1·367	1·677	1·341	1·646	1·317	1·616	1·294	1·587	1·271	1·560	1·250	1·534	1·230	1·510	1·211	1·486
16	1·494	2·086	1·464	2·043	1·435	2·004	1·408	1·966	1·382	1·930	1·358	1·896	1·335	1·864	1·313	1·833	1·292	1·804	1·272	1·776
17	1·567	2·470	1·535	2·420	1·505	2·372	1·477	2·328	1·450	2·286	1·425	2·246	1·401	2·208	1·377	2·171	1·355	2·136	1·334	2·103
18	1·631	2·883	1·599	2·825	1·567	2·770	1·538	2·718	1·510	2·669	1·484	2·622	1·458	2·577	1·434	2·535	1·411	2·494	1·389	2·456
19	1·702	3·351	1·668	3·284	1·636	3·220	1·605	3·160	1·576	3·103	1·548	3·048	1·522	2·996	1·497	2·947	1·473	2·900	1·450	2·855
20	1·764	3·848	1·728	3·771	1·695	3·698	1·664	3·629	1·633	3·563	1·605	3·500	1·577	3·441	1·551	3·385	1·527	3·331	1·503	3·279

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—) 1250		1300		1350		1400		1450		1500		1550		1600		1650		1700	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
21	1·829	4·398	1·792	4·310	1·757	4·226	1·724	4·147	1·692	4·072	1·663	4·001	1·635	3·933	1·608	3·869	1·583	3·807	1·558	3·748
22	1·907	5·034	1·854	4·894	1·822	4·810	1·784	4·710	1·752	4·625	1·721	4·544	1·692	4·467	1·668	4·404	1·638	4·324	1·613	4·257
23	1·954	5·639	1·915	5·526	1·878	5·419	1·843	5·318	1·810	5·221	1·778	5·131	1·748	5·044	1·720	4·962	1·692	4·881	1·666	4·806
24	2·016	6·333	1·976	6·206	1·937	6·186	1·901	5·973	1·867	5·865	1·834	5·763	1·803	5·665	1·774	5·573	1·746	5·485	1·719	5·400
26	2·136	7·876	2·094	7·719	2·053	7·570	2·015	7·429	1·979	7·295	1·944	7·168	1·911	7·047	1·880	6·932	1·850	6·822	1·822	6·717
27	2·196	8·730	2·153	8·555	2·110	8·389	2·071	8·232	2·033	8·084	1·998	7·944	1·964	7·810	1·932	7·683	1·902	7·561	1·872	7·444
30	2·367	11·62	2·320	11·39	2·275	11·17	2·233	10·96	2·193	10·77	2·155	10·58	2·119	10·40	2·084	10·23	2·052	10·07	2·019	9·915
33	2·534	15·05	2·483	14·75	2·435	14·46	2·390	14·19	2·347	13·94	2·306	13·70	2·268	13·47	2·231	13·25	2·196	13·04	2·162	12·84
36	2·693	19·04	2·640	18·66	2·589	18·30	2·541	17·96	2·496	17·64	2·453	17·34	2·412	17·05	2·372	16·77	2·335	16·50	2·299	16·25
39	2·848	23·63	2·792	23·16	2·738	22·72	2·688	22·30	2·640	21·90	2·594	21·52	2·551	21·16	2·510	20·82	2·470	20·49	2·432	20·18
42	2·998	28·85	2·939	28·27	2·883	27·74	2·830	27·23	2·780	26·74	2·732	26·28	2·686	25·84	2·643	25·43	2·601	25·03	2·562	24·65
45	3·145	34·74	3·083	34·05	3·024	33·40	2·968	32·78	2·916	32·27	2·865	31·65	2·816	31·11	2·772	30·62	2·729	30·15	2·688	29·68
48	3·288	41·32	3·223	40·50	3·161	39·73	3·103	39·00	3·048	38·30	2·996	37·64	2·946	37·02	2·998	36·42	2·853	35·83	2·810	35·31
51	3·427	48·62	3·359	47·65	3·295	46·75	3·235	45·89	3·177	45·07	3·123	44·30	3·070	43·56	3·021	42·86	2·974	42·19	2·929	41·55
54	3·663	56·66	3·492	55·54	3·426	54·49	3·363	53·49	3·303	52·54	3·247	51·64	3·193	50·78	3·142	49·96	3·092	49·18	3·046	48·44
57	3·695	65·48	3·623	64·19	3·554	62·97	3·489	61·82	3·427	60·72	3·368	59·68	3·312	58·69	3·259	57·75	3·208	56·85	3·160	55·99
60	3·825	75·11	3·750	73·63	3·678	72·23	3·611	70·89	3·547	69·65	3·488	68·46	3·429	67·33	3·374	66·25	3·321	65·21	3·271	64·23
63	3·953	85·56	3·875	83·88	3·801	82·29	3·732	80·78	3·666	79·35	3·603	78·00	3·543	76·71	3·486	75·48	3·432	74·30	3·381	73·18
66	4·078	96·87	3·997	94·97	3·921	93·14	3·850	91·46	3·782	89·84	3·717	88·31	3·655	86·85	3·597	85·46	3·541	84·12	3·488	82·87
69	4·200	109·1	4·117	106·9	4·039	104·9	3·965	103·0	3·895	101·2	3·829	99·43	3·767	97·79	3·706	96·22	3·648	94·73	3·593	93·30
72	4·320	122·2	4·235	119·8	4·155	117·5	4·079	115·3	4·007	113·3	3·939	111·4	3·874	109·5	3·812	107·8	3·753	106·1	3·696	104·5
78	4·554	151·1	4·465	148·2	4·381	145·4	4·301	142·7	4·225	140·2	4·153	137·8	4·085	135·5	4·019	133·4	3·957	131·3	3·898	129·3
84	4·781	184·0	4·687	180·4	4·599	177·0	4·515	173·8	4·436	170·7	4·360	167·8	4·289	165·1	4·220	162·4	4·155	159·9	4·093	157·5
90	5·001	220·9	4·903	216·6	4·811	212·5	4·723	208·7	4·640	205·0	4·562	201·5	4·487	198·2	4·415	195·1	4·347	192·0	4·282	189·1
96	5·215	262·1	5·113	257·0	5·017	252·2	4·925	247·6	4·839	243·2	4·757	239 1	4·679	235·2	4·605	231·5	4·533	227·9	4·466	224·5
102	5·423	307·7	5·316	301·6	5·216	296·0	5·122	290·7	5 032	285·6	4·947	280·7	4·866	276·1	4·789	271·8	4·715	267·6	4·645	263·6
108	5·626	357·9	5·516	350·9	5·412	344·3	5·314	338·0	5·220	332·1	5·133	326·5	5·049	321·2	4·969	316·1	4·891	311·2	4·819	306·6
114	5·823	412·7	5·710	404·7	5·602	397·1	5·501	389·9	5·405	383·1	5·313	376·6	5·226	370·5	5·143	364·7	5·064	359·1	4·989	353·7
120	6·017	472·6	5·900	463·4	5·789	454·7	5·684	446·4	5·585	438·6	5·491	431·2	5·401	424·2	5·315	417·5	5·233	411·1	5·155	404·9

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	SINE OF INCLINATION. (1 over:—)																			
	1750		1800		1850		1900		1950		2000		2050		2100		2150		2200	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
10	·8718	·4755	·8588	·4684	·8464	·4616	·8344	·4550												
11	·9394	·6200	·9254	·6107	·9120	·6018	·8990	·5933	·8866	·5851	·8747	·5772	·8631	·5696	·8520	·5623	·8413	·5552		
12	1·005	·7894	·9901	·7776	·9758	·7664	·9620	·7555	·9487	·7451	·9360	·7351	·9236	·7254	·9117	·7160	·9007	·7074	·8892	·6984
13	1·069	·9854	1·053	·9707	1·038	·9567	1·023	·9433	1·009	·9303	·9957	·9178	·9826	·9057	·9701	·8942	·9579	·8829	·9461	·8721
14	1·132	1·207	1·115	1·189	1·099	1·172	1·083	1·155	1·068	1·140	1·054	1·124	1·040	1·110	1·027	1·095	1·014	1·081	1·002	1·068
15	1·193	1·464	1·176	1·443	1·158	1·421	1·141	1·401	1·126	1·382	1·111	1·363	1·097	1·346	1·083	1·329	1·069	1·312	1·056	1·296
16	1·252	1·749	1·234	1·723	1·217	1·699	1·200	1·676	1·183	1·652	1·167	1·629	1·152	1·608	1·137	1·588	1·123	1·568	1·109	1·549
17	1·314	2·071	1·295	2·041	1·277	2·012	1·258	1·983	1·241	1·956	1·225	1·930	1·209	1·904	1·193	1·881	1·178	1·858	1·162	1·832
18	1·368	2·418	1·348	2·383	1·329	2·349	1·310	2·316	1·293	2·284	1·275	2·254	1·259	2·224	1·243	2·196	1·227	2·169	1·212	2·143
19	1·428	2·812	1·407	2·771	1·387	2·731	1·368	2·693	1·349	2·656	1·331	2·621	1·314	2·587	1·297	2·554	1·281	2·522	1·260	2·492
20	1·480	3·229	1·458	3·182	1·438	3·136	1·418	3·093	1·398	3·051	1·380	3·010	1·362	2·971	1·345	2·934	1·328	2·898	1·312	2·862
21	1·535	3·691	1·512	3·637	1·491	3·585	1·470	3·535	1·450	3·487	1·431	3·442	1·412	3·397	1·394	3·354	1·376	3·312	1·360	3·272
22	1·588	4·193	1·565	4·131	1·543	4·072	1·521	4·016	1·501	3·961	1·481	3·909	1·462	3·858	1·443	3·810	1·425	3·763	1·408	3·717
23	1·641	4·735	1·617	4·665	1·594	4·596	1·572	4·535	1·551	4·474	1·530	4·415	1·510	4·357	1·491	4·303	1·473	4·250	1·455	4·198
24	1·692	5·318	1·668	5·241	1·644	5·166	1·622	5·094	1·600	5·026	1·579	4·995	1·558	4·895	1·539	4·834	1·520	4·774	1·501	4·715
26	1·794	6·616	1·768	6·520	1·743	6·427	1·719	6·338	1·696	6·253	1·674	6·170	1·652	6·091	1·631	6·015	1·611	5·941	1·592	5·869
27	1·844	7·333	1·817	7·226	1·792	7·124	1·767	7·025	1·743	6·930	1·720	6·839	1·698	6·751	1·677	6·667	1·656	6·585	1·636	6·506
30	1·990	9·767	1·961	9·624	1·933	9·489	1·905	9·358	1·881	9·232	1·856	9·111	1·832	8·994	1·809	8·881	1·787	8·773	1·765	8·668
33	2·130	12·65	2·099	12·47	2·069	12·29	2·041	12·12	2·012	11·95	1·987	11·80	1·962	11·65	1·937	11·51	1·914	11·37	1·891	11·23
36	2·265	16·01	2·232	15·78	2·201	15·56	2·171	15·34	2·142	15·14	2·114	14·94	2·087	14·75	2·061	14·57	2·036	14·39	2·012	14·22
39	2·396	19·88	2·362	19·59	2·329	19·32	2·297	19·05	2·267	18·80	2·236	18·55	2·208	18·32	2·181	18·09	2·154	17·87	2·129	17·66
42	2·524	24·28	2·487	23·93	2·452	23·59	2·419	23·27	2·387	22·96	2·356	22·66	2·326	22·37	2·297	22·09	2·269	21·83	2·242	21·57
45	2·648	29·24	2·609	28·82	2·573	28·42	2·538	28·03	2·504	27·66	2·472	27·30	2·440	26·95	2·410	26·62	2·381	26·30	2·353	25·99
48	2·768	34·79	2·728	34·29	2·690	33·81	2·654	33·35	2·618	32·90	2·594	32·48	2·552	32·07	2·520	31·67	2·490	31·29	2·460	30·92
51	2·886	40·94	2·844	40·35	2·805	39·79	2·767	39·25	2·730	38·73	2·695	38·23	2·661	37·74	2·628	37·28	2·596	36·83	2·566	36·41
54	3·001	47·73	2·958	47·04	2·917	46·39	2·877	45·76	2·839	45·15	2·802	44·57	2·767	44·00	2·733	43·46	2·700	42·94	2·668	42·44
57	3·113	55·17	3·069	54·38	3·026	53·62	2·985	52·89	2·945	52·19	2·907	51·52	2·871	50·87	2·836	50·25	2·802	49·64	2·769	49·07
60	3·223	63·29	3·177	62·38	3·133	61·52	3·091	60·68	3·050	59·88	3·010	59·11	2·973	58·37	2·936	57·65	2·901	56·96	2·867	56·29
63	3·331	72·11	3·283	71·08	3·238	70·09	3·194	69·14	3·152	68·23	3·111	67·35	3·072	66·51	3·035	65·69	2·998	64·91	2·963	64·15
66	3·437	81·65	3·388	80·48	3·341	79·37	3·296	78·30	3·252	77·27	3·210	76·27	3·170	75·32	3·131	74·40	3·094	73·51	3·058	72·65
69	3·541	91·94	3·490	90·62	3·442	89·37	3·395	88·16	3·351	87·00	3·308	85·89	3·266	84·81	3·226	83·78	3·188	82·78	3·150	81·80

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where $n = \cdot 013$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	1750		1800		1850		1900		1950		2000		2050		2100		2150		2200	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
72	3·642	103·0	3·590	101·5	3·541	100·1	3·493	98·76	3·447	97·46	3·403	96·22	3·360	95·01	3·319	93·85	3·280	92·73	3·241	91·65
78	3·841	127·5	3·786	125·6	3·734	123·9	3·684	122·2	3·636	120·6	3·589	119·1	3·544	117·6	3·501	116·2	3·459	114·8	3·419	113·5
84	4·033	155·2	3·976	153·0	3·921	150·9	3·868	148·9	3·818	146·9	3·769	145·0	3·722	143·2	3·677	141·5	3·633	139·8	3·591	138·2
90	4·220	186·4	4·160	183·8	4·103	181·3	4·048	178·8	3·995	176·5	3·944	174·2	3·895	172·1	3·848	170·0	3·802	168·0	3·758	166·0
96	4·401	221·2	4·339	218·1	4·280	215·1	4·222	212·2	4·167	209·4	4·114	206·8	4·062	204·2	4·013	201·7	3·966	199·3	3·920	197·0
102	4·577	259·7	4·513	256·1	4·451	252·6	4·391	249·2	4·334	245·9	4·279	242·8	4·226	239·8	4·175	236·9	4·125	234·1	4·077	231·4
108	4·749	302·1	4·682	297·9	4·618	293·8	4·556	289·9	4·497	286·1	4·440	282·5	4·385	279·0	4·332	275·6	4·281	272·3	4·231	269·2
114	4·917	348·5	4·848	313·6	4·781	338·9	4·718	334·4	4·656	330·1	4·597	325·9	4·540	321·8	4·486	318·0	4·433	314·2	4·382	310·6
120	5·081	399·0	5·010	393·4	4·941	388·1	4·875	382·9	4·812	377·9	4·751	373·1	4·692	368·5	4·636	364·1	4·581	359·8	4·528	355·6

Diameter in Inches.	Sine of Inclination. (1 over:—)																			
	2250		2300		2350		2400		2450		2500		2550		2600		2650		2700	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
12	·8785	·6900	·8682	·6819	·8581	·6739	·8482	·6662	·8389	·6589										
13	·9318	·8616	·9239	·8514	·9130	·8415	·9026	·8320	·8927	·8229	·8831	·8140	·8737	·8053	·8645	·7968	·8555	·7884		
14	·9897	1·056	·9781	1·043	·9668	1·031	·9558	1·020	·9453	1·008	·9351	·9974	·9251	·9867	·9155	·9764	·9060	·9663	·8969	·9566
15	1·043	1·280	1·031	1·266	1·019	1·252	1·008	1·237	·9967	1·223	·9859	1·210	·9755	1·197	·9653	1·184	·9554	1·172	·9458	1·161
16	1·096	1·530	1·083	1·512	1·070	1·494	1·059	1·478	1·047	1·462	1·036	1·446	1·025	1·431	1·014	1·416	1·004	1·402	·9936	1·388
17	1·151	1·813	1·137	1·792	1·123	1·771	1·111	1·751	1·098	1·732	1·087	1·713	1·076	1·695	1·064	1·678	1·053	1·661	1·042	1·644
18	1·198	2·117	1·184	2·092	1·170	2·068	1·157	2·045	1·144	2·023	1·132	2·001	1·120	1·980	1·109	1·959	1·097	1·939	1·086	1·920
19	1·251	2·462	1·236	2·433	1·221	2·405	1·208	2·379	1·195	2·353	1·182	2·328	1·170	2·303	1·157	2·279	1·146	2·256	1·134	2·234
20	1·296	2·828	1·281	2·795	1·266	2·763	1·252	2·733	1·238	2·703	1·225	2·674	1·212	2·646	1·200	2·619	1·188	2·592	1·176	2·565
21	1·344	3·233	1·328	3·196	1·313	3·159	1·299	3·124	1·284	3·090	1·271	3·056	1·258	3·025	1·245	2·994	1·232	2·963	1·220	2·934
22	1·391	3·673	1·375	3·630	1·360	3·689	1·345	3·549	1·330	3·511	1·316	3·574	1·302	3·437	1·289	3·401	1·276	3·367	1·263	3·334
23	1·438	4·148	1·421	4·101	1·405	4·054	1·390	4·009	1·374	3·966	1·360	3·923	1·346	3·882	1·332	3·842	1·318	3·803	1·305	3·765
24	1·483	4·661	1·466	4·607	1·449	4·554	1·433	4·504	1·417	4·455	1·402	4·408	1·388	4·362	1·374	4·317	1·360	4·274	1·347	4·231
26	1·573	5·800	1·555	5·733	1·538	5·668	1·521	5·606	1·506	5·544	1·488	5·486	1·472	5·429	1·457	4·373	1·442	5·320	1·429	5·266
27	1·617	6·430	1·599	6·356	1·580	6·284	1·563	6·214	1·546	6·147	1·527	6·082	1·513	6·018	1·498	5·956	1·483	5·896	1·469	5·838
30	1·745	8·566	1·725	8·468	1·705	8·372	1·687	8·284	1·668	8·191	1·651	8·105	1·634	8·021	1·617	7·939	1·601	7·860	1·585	7·783
33	1·869	11·10	1·847	10·97	1·826	10·85	1·806	10·73	1·787	10·61	1·768	10·51	1·750	10·39	1·732	10·29	1·715	10·19	1·697	10·09
36	1·988	14·05	1·965	13·89	1·943	13·73	1·922	13·58	1·901	13·44	1·881	13·30	1·862	13·16	1·843	13·03	1·825	12·90	1·807	12·77
39	2·104	17·45	2·080	17·25	2·056	17·06	2·034	16·88	2·012	16·69	1·991	16·53	1·971	16·35	1·951	16·19	1·932	16·03	1·913	15·87

TABLE 56 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

CIRCULAR SEWERS, PIPES AND CONDUITS.—RUNNING FULL. (Where n = ·013.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	Sine of Inclination. (1 over:—) 2250		2300		2350		2400		2450		2500		2550		2600		2650		2700	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
42	2·216	21·32	2·191	21·08	2·166	20·85	2·143	20·62	2·120	20·40	2·098	20·19	2·076	19·98	2·055	19·78	2·035	19·58	2·015	19·39
45	2·325	25·68	2·299	25·39	2·274	25·11	2·249	24·84	2·225	24·57	2·201	24·31	2·179	24·07	2·157	23·83	2·136	23·59	2·115	23·36
48	2·432	30·56	2·404	30·21	2·378	29·88	2·352	29·55	2·327	29·24	2·303	28·94	2·280	28·65	2·257	28·36	2·235	28·08	2·213	27·81
51	2·536	35·97	2·507	35·57	2·480	35·17	2·452	34·80	2·427	34·43	2·401	34·07	2·377	33·72	2·353	33·39	2·330	33·06	2·308	32·73
54	2·637	41·95	2·608	41·47	2·579	41·02	2·551	40·57	2·524	40·15	2·498	39·73	2·472	39·32	2·448	38·93	2·424	38·55	3·401	38·18
57	2·736	48·49	2·706	47·94	2·676	47·42	2·647	46·90	2·619	46·41	2·592	45·93	2·566	45·46	2·541	45·02	2·516	44·58	2·491	44·15
60	2·834	55·64	2·802	55·02	2·771	54·41	2·741	53·83	2·712	53·26	2·684	52·71	2·657	52·17	2·631	51·65	2·605	51·14	2·580	50·66
63	2·929	63·41	2·896	62·69	2·864	62·00	2·833	61·34	2·803	60·68	2·775	60·07	2·747	59·46	2·720	58·87	2·693	58·29	2·667	57·73
66	3·022	71·81	2·989	71·01	2·956	70·23	2·924	69·47	2·894	68·74	2·864	68·03	2·835	67·35	2·807	66·68	2·779	66·03	2·752	65·40
69	3·114	80·87	3·079	79·97	3·045	79·10	3·013	78·24	2·982	77·41	2·951	76·62	2·921	75·85	2·892	75·10	2·864	74·40	2·836	73·68
72	3·204	90·60	3·169	89·59	3·134	88·61	3·100	87·66	3·068	86·74	3·036	85·85	3·006	84·98	2·976	84·14	2·947	83·32	2·919	82·52
78	3·380	112·1	3·342	110·9	3·305	109·7	3·270	108·5	3·236	107·4	3·203	106·3	3·171	105·2	3·140	104·1	3·109	103·1	3·080	102·2
84	3·549	136·6	3·510	135·1	3·472	133·6	3·435	132·2	3·399	130·8	3·365	129·5	3·331	128·2	3·298	126·9	3·266	125·7	3·235	124·5
90	3·715	164·1	3·674	162·3	3·634	160·5	3·595	158·8	3·557	157·1	3·521	155·5	3·486	154·0	3·452	152·5	3·418	151·0	3·386	149·6
96	3·875	194·7	3·832	192·6	3·790	190·5	3·750	188·5	3·712	186·5	3·675	184·6	3·638	182·8	3·601	181·0	3·567	179·3	3·533	177·6
102	4·031	228·7	3·987	226·2	3·944	223·8	3·902	221·4	3·861	219·1	3·822	216·9	3·784	214·8	3·747	212·7	3·710	210·6	3·676	208·5
108	4·183	266·1	4·137	263·2	4·092	260·4	4·049	257·6	4·007	254·9	3·967	252·3	3·927	249·8	3·889	247·4	3·851	245·0	3·815	242·7
114	4·332	307·1	4·284	303·7	4·238	300·4	4·193	297·2	4·150	294·1	4·108	291·2	4·067	288·3	4·027	285·5	3·988	282·8	3·951	280·1
120	4·477	351·6	4·428	347·8	4·380	344·0	4·334	340·4	4·289	336·9	4·246	333·5	4·204	330·2	4·163	326·9	4·123	323·7	4·084	320·7

Diameter in Inches.	Sine of Inclination. (1 over:—) 2750		2800		2850		2900		2950		3000		3100		3200		3300		3400	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
14	·8878	·9469	·8793	·9378	·8708	·9287	·8624	·9196	·8529	·9097	·8467	·9031								
15	·9364	1·149	·9273	1·139	·9184	1·127	·9097	1·116	·9013	1·106	·8931	1·096	·8774	1·077	·8620	1·058	·8474	1·040		
16	·9837	1·374	·9742	1·360	·9647	1·347	·9558	1·334	·9471	1·322	·9384	1·310	·9217	1·287	·9057	1·265	·8906	1·244	·8762	1·224
17	1·032	1·624	1·023	1·612	1·013	1·596	1·003	1·581	·9922	1·564	·9851	1·553	·9654	1·522	·9510	1·498	·9353	1·474	·9200	1·450
18	1·076	1·901	1·068	1·883	1·055	1·865	1·045	1·847	1·035	1·830	1·027	1·813	1·008	1·782	·9910	1·751	·9746	1·722	·9588	1·694
19	1·123	2·212	1·112	2·190	1·102	2·169	1·091	2·148	1·081	2·129	1·072	2·110	1·053	2·067	1·038	2·037	1·017	2·004	1·000	1·971
20	1·164	2·540	1·153	2·516	1·142	2·492	1·132	2·468	1·122	2·419	1·111	2·424	1·091	2·381	1·073	2·341	1·055	2·302	1·038	2·265
21	1·208	2·905	1·196	2·878	1·185	2·848	1·173	2·823	1·161	2·792	1·153	2·772	1·132	2·723	1·113	2·677	1·095	2·633	1·077	2·590
22	1·250	3·301	1·238	3·269	1·227	3·238	1·216	3·208	1·205	3·179	1·194	3·150	1·172	3·095	1·152	3·043	1·133	2·992	1·115	2·944

…RUNNING FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Diameter in Inches.	2750		2800		2850		2900		2950		3000		3100		3200		3300		3400	
Sine of Inclination. (1 over :—)	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
23	1·292	3·729	1·280	3·693	1·268	3·658	1·256	3·625	1·243	3·592	1·231	3·559	1·209	3·498	1·190	3·438	1·171	3·381	1·153	3·327
24	1·334	4·190	1·321	4·150	1·308	4·107	1·296	4·070	1·285	4·036	1·273	4·000	1·251	3·920	1·229	3·863	1·210	3·800	1·191	3·739
26	1·415	5·216	1·401	5·166	1·388	5·117	1·375	5·069	1·362	5·024	1·350	4·978	1·326	4·891	1·304	4·809	1·283	4·731	1·263	4·656
27	1·454	5·781	1·440	5·726	1·426	5·673	1·413	5·621	1·400	5·570	1·388	5·520	1·365	5·422	1·342	5·332	1·319	5·246	1·298	5·163
30	1·570	7·707	1·555	7·634	1·540	7·562	1·526	7·493	1·513	7·426	1·499	7·359	1·473	7·232	1·448	7·111	1·425	6·995	1·402	6·884
33	1·681	10·00	1·665	9·894	1·650	9·801	1·635	9·713	1·620	9·626	1·606	9·539	1·579	9·373	1·552	9·217	1·527	9·068	1·503	8·925
36	1·789	12·65	1·773	12·53	1·757	12·41	1·741	12·30	1·725	12·19	1·710	12·09	1·680	11·88	1·652	11·68	1·626	11·49	1·600	11·31
39	1·894	15·72	1·876	15·57	1·858	15·41	1·842	15·28	1·826	15·15	1·809	15·02	1·778	14·76	1·749	14·51	1·721	14·28	1·694	14·06
42	1·996	19·21	1·977	19·03	1·959	18·85	1·941	18·67	1·924	18·51	1·907	18·35	1·875	17·99	1·844	17·74	1·813	17·46	1·785	17·18
45	2·095	23·14	2·075	22·92	2·055	22·70	2·037	22·50	2·020	22·31	2·003	22·12	1·968	21·73	1·935	21·37	1·904	21·03	1·875	20·70
48	2·192	27·54	2·171	27·28	2·150	27·02	2·131	26·78	2·113	26·56	2·095	26·32	2·059	25·88	2·025	25·45	1·993	25·03	1·962	24·64
51	2·286	32·43	2·264	32·13	2·243	31·83	2·223	31·54	2·203	31·26	2·184	30·98	2·147	30·46	2·112	29·96	2·079	29·48	2·047	29·03
54	2·378	37·81	2·356	37·47	2·334	37·13	2·313	36·79	2·293	36·47	2·273	36·15	2·234	35·54	2·198	34·95	2·163	34·40	2·129	33·86
57	2·467	43·72	2·445	43·32	2·423	42·93	2·401	42·54	2·380	42·18	2·360	41·80	2·319	41·10	2·281	40·43	2·245	39·78	2·211	39·17
60	2·556	50·18	2·532	49·72	2·508	49·27	2·487	48·82	2·465	48·40	2·443	46·88	2·401	47·16	2·362	46·39	2·326	45·65	2·290	44·95
63	2·042	57·19	2·618	56·67	2·593	56·15	2·569	55·63	2·546	55·13	2·523	54·63	2·483	53·77	2·444	52·89	2·405	52·06	2·368	51·26
66	2·727	64·78	2·702	64·19	2·677	63·60	2·653	63·02	2·629	62·45	2·606	61·90	2·562	60·90	2·520	59·91	2·481	58·96	2·444	58·06
69	2·809	72·97	2·784	72·30	2·758	71·63	2·733	70·97	2·709	70·32	2·685	69·68	2·631	68·48	2·599	67·52	2·558	66·42	2·519	65·40
72	2·892	81·75	2·865	81·00	2·839	80·27	2·813	79·84	2·787	78·82	2·762	78·12	2·719	76·88	2·675	75·64	2·032	74·44	2·591	73·29
78	3·051	101·3	3·023	100·4	2·995	99·38	2·969	98·52	2·944	97·67	2·919	96·83	2·869	95·21	2·823	93·67	2·278	92·19	2·736	90·80
84	3·205	123·3	3·176	122·2	3·147	121·1	3·118	120·0	3·090	118·9	3·064	117·9	3·014	116·0	2·966	114·2	2·920	112·4	2·875	110·7
90	3·355	148·2	3·324	146·9	3·294	145·5	3·264	144·2	3·235	143·0	3·206	141·8	3·156	139·1	3·106	137·2	3·057	135·1	3·010	133·0
96	3·500	175·9	3·468	174·3	3·438	172·7	3·406	171·2	3·377	169·7	3·348	168·3	3·291	165·5	3·241	162·9	3·191	160·4	3·142	158·0
102	3·642	206·5	3·609	204·7	3·576	202·9	3·544	201·1	3·514	199·3	3·484	197·7	3·426	194·5	3·372	191·4	3·320	188·4	3·270	185·6
108	3·780	240·5	3·746	238·3	3·712	236·1	3·679	234·1	3·647	232·1	3·616	230·1	3·557	226·3	3·500	222·7	3·446	219·3	3·394	216·0
114	3·914	277·4	3·879	275·0	3·844	272·6	3·811	270·2	3·779	267·9	3·747	265·6	3·685	261·2	3·626	257·0	3·570	253·1	3·517	249·3
120	4·047	317·8	4·010	315·0	3·974	312·2	3·940	309·4	3·907	306·8	3·873	304·2	3·809	299·2	3·749	294·4	3·691	289·9	3·636	285·6

Sine of Inclination. (1 over 3500 :—)

Diam.	V.	Q.
16″	·8624	1·204
17″	·9053	1·428
18″	·9436	1·667
19″	·9854	1·940
20″	1·022	2·229
21″	1·060	2·551
22″	1·098	2·898
23″	1·135	3·275
24″	1·171	3·681
26″	1·243	4·583
27″	1·278	5·082
30″	1·380	6·778
33″	1·480	8·788
36″	1·575	11·14
39″	1·668	13·84
42″	1·758	16·92
45″	1·846	20·39
48″	1·932	24·28
51″	2·016	28·60
54″	2·097	33·36
57″	2·177	38·59
60″	2·255	44·29
63″	2·338	50·49
66″	2·407	57·20
69″	2·481	64·43
72″	2·552	72·19
78″	2·696	89·45
84″	2·832	109·0
90″	2·966	131·0
96″	3·096	155·6
102″	3·222	182·8
108″	3·343	212·8
114″	3·465	245·6
120″	3·583	281·4

TABLE 57.—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where $n = \cdot 015$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over :—) 100		150		200		250		300		350		400		450		500	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	4·313	3·259	3·518	2·659	3·044	2·301	2·720	2·056	2·481	1·875	2·295	1·735	2·145	1·621	2·020	1·527	1·915	1·447
1′ 2″ × 1′ 9″	4·848	4·987	3·955	4·069	3·423	3·521	3·059	3·146	2·789	2·870	2·581	2·655	2·412	2·481	2·272	2·337	2·154	2·216
1′ 4″ × 2′ 0″	5·359	7·200	4·372	5·874	3·784	5·084	3·381	4·543	3·084	4·144	2·853	3·834	2·667	3·583	2·512	3·376	2·382	3·200
1′ 6″ × 2′ 3″	5·848	9·945	4·772	8·114	4·130	7·023	3·691	6·276	3·367	5·725	3·115	5·297	2·911	4·951	2·743	4·664	2·600	4·422
1′ 8″ × 2′ 6″	6·320	13·27	5·157	10·83	4·463	9·370	3·989	8·375	3·639	7·640	3·367	7·068	3·147	6·607	2·965	6·225	2·811	5·902
1′ 10″ × 2′ 9″	6·775	17·21	5·528	14·04	4·786	12·16	4·277	10·86	3·902	9·911	3·610	9·170	3·375	8·572	3·180	8·076	3·014	7·657
2′ 0″ × 3′ 0″	7·215	21·81	5·888	17·80	5·096	15·41	4·555	13·77	4·156	12·56	3·845	11·62	3·595	10·87	3·386	10·24	3·211	9·708
2′ 2″ × 3′ 3″	7·642	27·11	6·236	22·13	5·398	19·15	4·825	17·12	4·402	15·62	4·073	14·45	3·808	13·51	3·588	12·73	3·402	12·07
2′ 4″ × 3′ 6″	8·057	33·15	6·575	27·06	5·692	23·42	5·099	20·98	4·642	19·10	4·295	17·67	4·015	16·52	3·784	15·57	3·588	14·76
2′ 6″ × 3′ 9″	8·461	39·97	6·905	32·62	5·977	28·23	5·343	25·24	4·875	23·03	4·511	21·31	4·218	19·92	3·972	18·76	3·768	17·80
2′ 8″ × 4′ 0″	8·855	47·59	7·227	38·84	6·256	33·62	5·592	30·06	5·103	27·42	4·722	25·38	4·415	23·73	4·160	22·36	3·945	21·20
2′ 10″ × 4′ 3″	9·240	56·06	7·541	45·75	6·528	39·61	5·836	35·41	5·325	32·31	4·927	29·90	4·607	27·95	4·342	26·34	4·117	24·98
3′ 0″ × 4′ 6″	9·616	65·41	7·849	53·39	6·794	46·22	6·074	41·32	5·542	37·70	5·129	34·89	4·795	32·62	4·519	30·74	4·285	29·15
3′ 2″ × 4′ 9″	9·984	75·67	8·149	61·76	7·055	53·47	6·307	47·80	5·755	43·62	5·326	40·36	4·980	37·74	4·693	35·57	4·450	33·73
3′ 4″ × 5′ 0″	10·35	86·87	8·443	70·91	7·310	61·39	6·535	54·88	5·963	50·08	5·519	46·34	5·160	43·33	4·864	40·85	4·612	38·73
3′ 6″ × 5′ 3″			8·732	80·85	7·560	69·99	6·799	62·57	6·167	57·10	5·708	52·84	5·337	49·41	5·030	46·57	4·770	44·16
3′ 8″ × 5′ 6″			9·016	91·61	7·807	79·33	6·938	70·91	6·368	64·71	5·893	59·89	5·511	56·00	5·194	52·77	4·925	50·05
3′ 10″ × 5′ 9″			9·294	103·2	8·047	89·37	7·194	79·90	6·565	72·91	6·076	67·48	5·681	63·10	5·355	59·47	5·078	56·40
4′ 0″ × 6′ 0″			9·567	115·7	8·283	100·4	7·406	89·56	6·757	81·71	6·255	75·64	5·849	70·73	5·512	66·66	5·228	63·22
4′ 2″ × 6′ 3″			9·836	129·1	8·516	111·7	7·614	99·90	6·948	91·17	6·431	84·38	6·013	78·91	5·668	74·35	5·375	70·53
4′ 4″ × 6′ 6″			10·10	143·3	8·745	124·1	7·819	111·0	7·135	101·3	6·604	93·72	6·176	87·65	5·821	82·61	5·520	78·34
4′ 6″ × 6′ 9″					8·971	137·3	8·021	122·8	7·320	112·0	6·775	103·7	6·335	96·96	5·971	91·39	5·663	86·67
4′ 8″ × 7′ 0″					9·193	151·3	8·220	135·3	7·501	123·5	6·943	114·3	6·493	106·9	6·120	100·7	5·804	95·53
4′ 10″ × 7′ 3″					9·411	166·2	8·415	148·6	7·680	135·6	7·108	125·5	6·647	117·4	6·265	110·6	5·942	104·9
5′ 0″ × 7′ 6″					9·627	181·9	8·608	162·7	7·856	148·4	7·272	137·4	6·800	128·5	6·410	121·1	6·079	114·9
5′ 2″ × 7′ 9″					9·840	198·5	8·811	177·8	8·030	162·0	7·432	150·0	6·951	140·2	6·552	132·2	6·214	125·4
5′ 4″ × 8′ 0″					10·05	216·0	8·986	193·2	8·201	176·3	7·591	163·2	7·099	152·6	6·691	143·9	6·347	136·4
5′ 6″ × 8′ 3″							9·172	209·7	8·371	191·4	7·748	177·1	7·246	165·7	6·830	156·2	6·478	148·1
5′ 8″ × 8′ 6″							9·355	227·0	8·538	207·2	7·903	191·8	7·391	179·4	6·967	169·1	6·608	160·4
5′ 10″ × 8′ 9″							9·535	245·2	8·703	223·8	8·056	207·2	7·534	193·8	7·098	182·5	6·736	173·2
6′ 0″ × 9′ 0″							9·714	264·3	8·866	241·2	8·207	223·3	7·675	208·8	7·235	196·9	6·862	186·7

TABLE 57 (Co...

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	SINE OF INCLINATION. (1 over:—)																	
	550		600		650		700		750		800		850		900		950	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	1·825	1·379	1·745	1·319	1·675	1·266	1·613	1·219	1·557	1·177	1·506	1·138	1·460	1·103	1·417	1·071	1·378	1·042
1′ 2″ × 1′ 9″	2·052	2·111	1·963	2·019	1·885	1·939	1·815	1·857	1·751	1·802	1·694	1·743	1·643	1·690	1·595	1·641	1·551	1·596
1′ 4″ × 2′ 0″	2·269	3·049	2·171	2·917	2·084	2·801	2·007	2·697	1·937	2·603	1·874	2·518	1·817	2·441	1·765	2·371	1·716	2·306
1′ 6″ × 2′ 3″	2·478	4·213	2·370	4·031	2·276	3·870	2·192	3·726	2·116	3·597	2·047	3·481	1·984	3·375	1·927	3·277	1·875	3·187
1′ 8″ × 2′ 6″	2·679	5·623	2·563	5·380	2·461	5·166	2·370	4·974	2·288	4·803	2·214	4·647	2·146	4·505	2·084	4·375	2·027	4·256
1′ 10″ × 2′ 9″	2·872	7·296	2·748	6·981	2·638	6·704	2·541	6·455	2·453	6·232	2·373	6·030	2·302	5·847	2·236	5·678	2·174	5·523
2′ 0″ × 3′ 0″	3·060	9·250	2·928	8·852	2·811	8·499	2·707	8·185	2·614	7·903	2·530	7·647	2·453	7·414	2·382	7·201	2·317	7·005
2′ 2″ × 3′ 3″	3·241	11·50	3·102	11·01	2·979	10·57	2·869	10·18	2·769	9·827	2·680	9·510	2·599	9·221	2·524	8·956	2·455	8·712
2′ 4″ × 3′ 6″	3·419	14·07	3·272	13·46	3·142	12·93	3·026	12·45	2·921	12·02	2·827	11·63	2·741	11·28	2·663	10·96	2·590	10·66
2′ 6″ × 3′ 9″	3·591	16·96	3·437	16·23	3·300	15·58	3·178	15·01	3·069	14·50	2·970	14·03	2·880	13·60	2·797	13·21	2·721	12·86
2′ 8″ × 4′ 0″	3·759	20·20	3·598	19·34	3·455	18·57	3·327	17·88	3·213	17·26	3·109	16·71	3·015	16·20	2·929	15·74	2·849	15·32
2′ 10″ × 4′ 3″	3·923	23·80	3·755	22·78	3·606	21·88	3·473	21·07	3·354	20·35	3·246	19·69	3·147	19·09	3·057	18·55	2·974	18·05
3′ 0″ × 4′ 6″	4·084	27·78	3·909	26·59	3·754	25·54	3·616	24·59	3·491	23·74	3·379	22·98	3·277	22·29	3·183	21·65	3·097	21·06
3′ 2″ × 4′ 9″	4·241	32·14	4·059	30·76	3·899	29·55	3·755	28·46	3·626	27·48	3·509	26·59	3·403	25·79	3·306	25·06	3·216	24·38
3′ 4″ × 5′ 0″	4·395	36·91	4·206	35·32	4·040	33·93	3·891	32·68	3·758	31·56	3·637	30·54	3·527	29·62	3·426	28·77	3·334	27·99
3′ 6″ × 5′ 3″	4·546	42·09	4·351	40·28	4·179	38·69	4·025	37·27	3·887	35·99	3·762	34·83	3·649	33·78	3·544	32·82	3·447	31·93
3′ 8″ × 5′ 6″	4·694	47·70	4·493	45·65	4·316	43·85	4·157	42·24	4·014	40·79	3·885	39·48	3·768	38·29	3·661	37·20	3·562	36·19
3′ 10″ × 5′ 9″	4·840	53·75	4·632	51·45	4·450	49·42	4·286	47·60	4·139	45·97	4·006	44·49	3·885	43·15	3·775	41·92	3·673	40·79
4′ 0″ × 6′ 0″	4·983	60·26	4·769	57·67	4·581	55·40	4·413	53·36	4·261	51·53	4·125	49·89	4·000	48·38	3·886	47·00	3·781	45·73
4′ 2″ × 6′ 3″	5·123	67·23	4·904	64·34	4·710	61·81	4·537	59·53	4·382	57·49	4·241	55·65	4·114	53·98	3·997	52·44	3·889	51·02
4′ 4″ × 6′ 6″	5·262	74·68	5·036	71·48	4·838	68·66	4·660	66·13	4·500	63·87	4·356	61·83	5·225	59·97	4·105	58·26	3·994	56·68
4′ 6″ × 6′ 9″	5·398	82·62	5·167	79·08	4·963	75·96	4·781	73·17	4·617	70·67	4·470	68·41	4·335	66·34	4·212	64·46	4·099	62·72
4′ 8″ × 7′ 0″	5·533	91·06	5·296	87·16	5·087	83·73	4·900	80·65	4·733	77·90	4·581	75·40	4·443	73·13	4·317	71·05	4·201	69·14
4′ 10″ × 7′ 3″	5·664	100·0	5·422	95·73	5·208	91·96	5·017	88·58	4·845	85·55	4·690	82·82	4·549	80·32	4·420	78·04	4·301	75·94
5′ 0″ × 7′ 6″	5·795	109·5	5·547	104·8	5·329	100·7	5·133	96·99	4·958	93·67	4·799	90·67	4·655	87·95	4·522	85·45	4·400	83·15
5′ 2″ × 7′ 9″	5·923	119·5	5·670	114·4	5·447	109·9	5·247	105·8	5·068	102·2	4·906	98·97	4·758	96·00	4·623	93·27	4·499	90·76
5′ 4″ × 8′ 0″	6·050	130·1	5·791	124·5	5·563	119·6	5·359	115·2	5·176	111·3	5·011	107·7	4·860	104·4	4·722	101·5	4·595	98·79
5′ 6″ × 8′ 3″	6·175	141·2	5·911	135·2	5·679	129·8	5·471	125·0	5·284	120·8	5·115	116·9	4·961	113·4	4·820	110·2	4·691	107·3
5′ 8″ × 8′ 3″	6·299	152·9	6·030	146·3	5·793	140·5	5·580	135·4	5·390	130·9	5·218	126·7	5·061	122·8	4·917	119·3	4·785	116·1
1′ 10″ × 8′ 9″	6·421	165·1	6·147	158·1	5·905	151·9	5·688	146·3	5·494	141·3	5·319	136·8	5·158	132·7	5·013	128·9	4·878	125·5
6′ 0″ × 9′ 0″	6·542	178·0	6·262	170·4	6·016	163·7	5·795	157·7	5·598	152·3	5·419	147·4	5·256	143·0	5·107	138·9	4·970	135·2

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where $n = \cdot 015$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—) 1000		1050		1100		1150		1200		1250		1300		1350		1400	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	1·342	1·015	1·309	·9892	1·278	·9656	1·249	·9436	1·221	·9229	1·195	·9035	1·171	·8852	1·148	·8679	1·127	·8515
1′ 2″ × 1′ 9″	1·510	1·554	1·472	1·514	1·437	1·478	1·405	1·445	1·375	1·414	1·346	1·384	1·319	1·356	1·293	1·330	1·269	1·305
1′ 4″ × 2′ 0″	1·671	2·246	1·630	2·190	1·591	2·133	1·555	2·089	1·521	2·044	1·482	2·002	1·459	1·961	1·431	1·923	1·404	1·887
1′ 6″ × 2′ 3″	1·826	3·104	1·780	3·027	1·737	2·956	1·698	2·890	1·662	2·827	1·628	2·768	1·595	2·712	1·564	2·659	1·534	2·609
1′ 8″ × 2′ 6″	1·974	4·145	1·925	4·042	1·879	3·947	1·837	3·858	1·798	3·775	1·760	3·696	1·726	3·621	1·692	3·551	1·660	3·485
1′ 10″ × 2′ 9″	2·118	5·380	2·066	5·247	2·017	5·123	1·972	5·007	1·929	4·899	1·888	4·797	1·850	4·701	1·814	4·610	1·780	4·524
2′ 0″ × 3′ 0″	2·257	6·824	2·201	6·655	2·149	6·498	2·101	6·352	2·056	6·215	2·013	6·085	1·972	5·962	1·935	5·848	1·899	5·740
2′ 2″ × 3′ 3″	2·392	8·486	2·333	8·277	2·278	8·081	2·227	7·900	2·179	7·730	2·134	7·570	2·091	7·419	2·050	7·276	2·012	7·141
2′ 4″ × 3′ 6″	2·523	10·39	2·461	10·13	2·403	9·888	2·349	9·665	2·298	9·458	2·251	9·262	2·206	9·077	2·163	8·902	2·123	8·737
2′ 6″ × 3′ 9″	2·651	12·53	2·586	12·22	2·525	11·93	2·468	11·66	2·415	11·41	2·365	11·17	2·318	10·95	2·273	10·74	2·231	10·54
2′ 8″ × 4′ 0″	2·775	14·92	2·707	14·55	2·643	14·21	2·584	13·89	2·529	13·59	2·477	13·31	2·428	13·05	2·381	12·80	2·337	12·56
2′ 10″ × 4′ 3″	2·897	17·58	2·826	17·14	2·760	16·74	2·699	16·37	2·641	16·02	2·586	15·69	2·535	15·38	2·486	15·09	2·440	14·81
3′ 0″ × 4′ 6″	3·018	20·52	2·944	20·02	2·874	19·55	2·809	19·10	2·749	18·70	2·693	18·31	2·640	17·95	2·589	17·61	2·541	17·28
3′ 2″ × 4′ 9″	3·133	23·75	3·056	23·16	2·985	22·62	2·918	22·11	2·856	21·63	2·797	21·19	2·741	20·78	2·689	20·39	2·640	20·01
3′ 4″ × 5′ 0″	3·249	27·27	3·169	26·60	3·095	25·98	3·025	25·40	2·960	24·85	2·899	24·34	2·842	23·86	2·788	23·41	2·736	22·98
3′ 6″ × 5′ 3″	3·358	31·11	3·277	30·35	3·201	29·64	3·130	28·97	3·063	28·35	2·000	27·77	2·941	27·22	2·884	26·70	2·831	26·21
3′ 8″ × 5′ 6″	3·470	35·26	3·385	34·40	3·307	33·60	3·233	32·85	3·163	32·14	3·098	31·48	3·037	30·86	2·980	30·27	2·925	29·72
3′ 10″ × 5′ 9″	3·578	39·74	3·490	38·77	3·410	37·86	3·334	37·01	3·262	36·22	3·195	35·48	3·132	34·78	8·073	34·12	3·016	33·49
4′ 0″ × 6′ 0″	3·684	44·55	3·595	43·46	3·511	42·45	3·433	41·51	3·360	40·62	3·291	39·78	3·225	39·00	3·163	38·26	2·105	37·56
4′ 2″ × 6′ 3″	3·788	49·71	3·696	48·50	3·610	47·37	3·530	46·31	3·454	45·32	3·383	44·49	3·316	43·52	3·254	42·70	3·195	41·92
4′ 4″ × 6′ 6″	3·891	55·23	3·796	53·88	3·708	52·62	3·626	51·45	3·549	50·36	3·475	49·32	3·407	48·35	3·342	47·43	3·281	46·56
4′ 6″ × 6′ 9″	3·993	61·11	3·895	59·62	3·805	58·23	3·719	56·93	3·639	55·72	3·563	54·58	3·493	53·51	3·428	52·49	3·367	51·53
4′ 8″ × 7′ 0″	4·093	67·36	3·993	65·72	3·900	64·19	3·814	62·77	3·733	61·44	3·656	60·18	3·584	58·99	3·516	57·86	3·451	56·80
4′ 10″ × 7′ 3″	4·191	73·99	4·089	72·19	3·994	70·50	3·905	68·94	3·822	67·47	3·744	66·09	3·670	64·79	3·600	63·56	3·534	62·40
5′ 0″ × 7′ 6″	4·287	81·02	4·183	79·05	4·086	77·21	3·996	75·50	3·911	73·89	3·830	72·38	3·755	70·96	3·684	69·62	3·617	68·34
5′ 2″ × 7′ 9″	4·384	88·43	4·277	86·28	4·178	84·28	4·085	82·41	3·997	80·66	3·915	79·01	3·839	77·45	3·766	75·98	3·698	74·60
5′ 4″ × 8′ 0″	4·477	96·26	4·368	93·91	4·267	91·73	4·173	89·71	4·084	87·81	4·000	86·01	3·921	84·31	3·848	82·71	3·778	81·21
5′ 6″ × 8′ 3″	4·571	104·6	4·460	102·0	4·357	99·58	4·260	97·37	4·169	95·31	4·084	93·37	4·004	91·54	3·929	89·81	3·857	88·17
5′ 8″ × 8′ 6″	4·663	113·2	4·549	110·4	4·445	107·8	4·346	105·4	4·253	103·2	4·166	101·1	4·084	99·12	4·007	97·27	3·934	95·51
5′ 10″ × 8′ 9″	4·753	122·3	4·637	119·3	4·530	116·5	4·430	113·9	4·336	111·5	4·248	109·2	4·165	107·1	4·086	105·1	4·011	103·2
6′ 0″ × 9′ 0″	4·843	131·7	4·725	128·5	4·616	125·5	4·514	122·7	4·418	120·1	4·328	117·7	4·243	115·4	4·163	113·2	4·087	111·1

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where $n = \cdot015$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over :—)																	
	1450		1500		1550		1600		1650		1700		1750		1800		1850	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	1·106	·8360	1·087	·8213	1·068	·8073	1·050	·7939	1·033	·7811	1·017	·7689	1·002	·7572	·9870	·7460	·9728	·7352
1′ 2″ × 1′ 9″	1·246	1·281	1·224	1·258	1·203	1·237	1·183	1·217	1·163	1·198	1·145	1·179	1·128	1·161	1·112	1·144	1·096	1·128
1′ 4″ × 2′ 0″	1·379	1·853	1·355	1·820	1·332	1·789	1·310	1·760	1·289	1·733	1·269	1·705	1·250	1·679	1·231	1·654	1·213	1·630
1′ 6″ × 2′ 3″	1·506	2·562	1·480	2·517	1·455	2·475	1·431	2·434	1·408	2·395	1·386	2·358	1·365	2·322	1·345	2·289	1·326	2·256
1′ 8″ × 2′ 6″	1·630	3·422	1·601	3·362	1·574	3·305	1·548	3·251	1·524	3·200	1·501	3·151	1·478	3·104	1·456	3·058	1·435	3·015
1′ 10″ × 2′ 9″	1·749	4·443	1·719	4·366	1·690	4·292	1·662	4·222	1·635	4·156	1·610	4·092	1·586	4·030	1·563	3·971	1·541	3·914
2′ 0″ × 3′ 0″	1·864	5·636	1·831	5·538	1·801	5·445	1·772	5·357	1·744	5·272	1·717	5·190	1·691	5·113	1·666	5·039	1·642	4·968
2′ 2″ × 3′ 3″	1·976	7·013	1·942	6·891	1·909	6·775	1·878	6·665	1·049	6·560	1·821	6·459	1·794	6·362	1·768	6·269	1·742	6·181
2′ 4″ × 3′ 6″	2·085	8·581	2·049	8·433	2·015	8·292	1·982	8·157	1·950	8·028	1·920	7·905	1·892	7·787	1·865	7·674	1·839	7·565
2′ 6″ × 3′ 9″	2·192	10·35	2·154	10·17	2·118	10·00	2·083	9·842	2·050	9·685	2·018	9·537	1·988	9·394	1·960	9·259	1·933	9·129
2′ 8″ × 4′ 0″	2·295	12·34	2·256	12·13	2·218	11·93	2·182	11·74	2·147	11·55	2·114	11·37	2·083	11·29	2·053	11·03	2·024	10·88
2′ 10″ × 4′ 3″	2·396	14·54	2·355	14·29	2·316	14·05	2·279	13·82	2·243	13·60	2·209	13·40	2·176	13·20	2·144	13·01	2·113	12·82
3′ 0″ × 4′ 6″	2·496	16·97	2·453	16·68	2·412	16·41	2·373	16·14	2·336	15·88	2·300	15·64	2·266	15·41	2·233	15·19	2·202	14·98
3′ 2″ × 4′ 9″	2·593	19·65	2·548	19·31	2·505	18·99	2·465	18·69	2·427	18·40	2·390	18·12	2·355	17·85	2·320	17·59	2·288	17·34
3′ 4″ × 5′ 0″	2·687	22·57	2·641	22·18	2·597	21·81	2·555	21·46	2·515	21·13	2·477	20·81	2·441	20·50	2·406	20·20	2·372	19·91
3′ 6″ × 5′ 3″	2·781	25·74	2·733	25·30	2·687	24·88	2·644	24·48	2·603	24·10	2·563	23·73	2·525	23·38	2·489	23·05	2·455	22·73
3′ 8″ × 5′ 6″	2·872	29·19	2·823	28·69	2·776	28·21	2·732	27·76	2·690	27·33	2·649	26·91	2·609	26·51	2·571	26·13	2·535	25·76
3′ 10″ × 5′ 9″	2·962	32·90	2·912	32·33	2·864	31·79	2·817	31·29	2·773	30·81	2·731	30·35	2·691	29·90	2·692	29·47	2·615	29·05
4′ 0″ × 6′ 0″	3·051	36·89	2·999	36·25	2·949	35·64	2·901	35·07	2·856	34·53	2·813	34·01	2·772	33·51	2·732	33·04	2·694	32·58
4′ 2″ × 6′ 3″	3·139	41·18	3·085	40·47	3·033	39·80	2 984	39 16	2·938	38·55	2·894	37·97	2·851	37·41	2·810	36·88	2·770	36·37
4′ 4″ × 6′ 6″	3·223	45·74	3·168	44·96	3·116	44·22	3·066	43·51	3·018	42·83	2·972	42·19	2·928	41·57	2·886	40·98	2·846	40·40
4′ 6″ × 6′ 9″	3·308	50 62	3 252	49·75	3 198	48·93	3·146	48·15	3·097	47·40	3·051	46·68	3·006	46·00	2·963	45·35	2·922	44·72
4′ 8″ × 7′ 0″	3·390	55·81	3·333	54·85	3·278	53 95	3·226	53·09	3·176	52·26	3·128	51·47	3·082	50·72	3·038	50·00	2·995	49·30
4′ 10″ × 7′ 3″	3·472	61·31	3·413	60·27	3·357	59·27	3·303	58·32	3·252	57·41	3·203	56·54	3·156	55·71	3·111	54·92	3·068	54·17
5′ 0″ × 7′ 6″	3·553	67·13	3·492	65·99	3·435	64·90	3·380	63·87	3·327	62·88	3·277	61·93	3·229	61·02	3·183	60·15	3·139	59·32
5′ 2″ × 7′ 9″	3·633	73·29	3·571	72·04	3·152	70·86	3·456	69·74	3·403	68·66	3·352	67·62	3·302	66·62	3·255	65·66	3·210	64·74
5′ 4″ × 8′ 0″	3·712	79·79	3·649	78·43	3·588	77·13	3·530	75·89	3·475	74·71	3·423	73·59	3·373	72·52	3·325	71·50	3·279	70·50
5′ 6″ × 8′ 3″	3·789	86·62	3·724	85·16	3·663	83·76	3·605	82·42	3·549	81·14	3·495	79·91	3·444	78·74	3·395	77·62	3·348	76·55
5′ 8″ × 8′ 6″	3·865	93·83	3·799	92·23	3·737	90·70	3·678	89·24	3·621	87·86	3·567	86·55	3·515	85·30	3·465	84·09	3·417	82·92
5′ 10″ × 8′ 9″	3·941	101·4	3·874	99·64	3·810	97·99	3·750	96·42	3·692	94·93	3·636	93·52	3·583	92·17	3·532	90·85	3·483	89·56
6′ 0″ × 9′ 0″	4·015	109·1	3·947	107·4	3·883	105·7	3·821	104·1	3·761	102·4	3·704	100·8	3·651	99·35	3·599	97·95	3·550	96·60

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	SINE OF INCLINATION. (1 over:—) 1900		1950		2000		2050		2100		2150		2200		2250		2300	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	·9591	·7249	·9459	·7149	·9333	·7053	·9211	·6961	·9093	·6872	·8979	·6786	·8869	·6703	·8763	·6623	·8660	·6545
1′ 2″ × 1′ 9″	1·081	1·112	1·067	1·096	1·053	1·081	1·039	1·068	1·025	1·054	1·012	1·041	·9995	1·028	·9876	1·016	·9761	1·004
1′ 4″ × 2′ 0″	1·196	1·607	1·180	1·585	1·164	1·564	1·149	1·544	1·134	1·525	1·120	1·506	1·107	1·488	1·094	1·470	1·081	1·453
1′ 6″ × 2′ 3″	1·308	2·225	1·290	2·195	1·273	2·166	1·257	2·138	1·241	2·111	1·226	2·085	1·211	2·059	1·196	2·034	1·182	2·010
1′ 8″ × 2′ 6″	1·415	2·973	1·396	2·933	1·378	2·894	1·360	2·856	1·343	2·820	1·326	2·785	1·310	2·752	1·295	2·720	1·280	2·688
1′ 10″ × 2′ 9″	1·520	3·860	1·499	3·808	1·479	3·758	1·460	3·710	1·442	3·663	1·424	3·618	1·407	3·575	1·391	3·533	1·375	3·492
2′ 0″ × 3′ 0″	1·619	4·899	1·597	4·833	1·576	4·768	1·556	4·718	1·537	4·649	1·519	4·592	1·501	4·537	1·484	4·484	1·467	4·432
2′ 2″ × 3′ 3″	1·718	6·095	1·695	6·014	1·673	5·936	1·652	5·860	1·632	5·787	1·612	5·716	1·592	5·647	1·573	5·581	1·555	5·517
2′ 4″ × 3′ 6″	1·814	7·461	1·789	7·361	1·765	7·265	1·742	7·173	1·720	7·084	1·699	6·997	1·680	6·913	1·661	6·832	1·642	6·754
2′ 6″ × 3′ 9″	1·907	9·004	1·881	8·884	1·856	8·769	1·832	8·656	1·809	8·547	1·787	8·443	1·766	8·340	1·746	8·247	1·726	8·153
2′ 8″ × 4′ 0″	1·996	10·73	1·970	10·59	1·945	10·45	1·920	10·32	1·896	10·19	1·873	10·06	1·851	9·945	1·829	9·830	1·808	9·718
2′ 10″ × 4′ 3″	2·084	12·64	2·057	12·47	2·030	12·31	2·004	12·16	1·979	12·01	1·955	11·87	1·933	11·73	1·910	11·59	1·188	11·46
3′ 0″ × 4′ 6″	2·172	14·77	2·143	14·57	2·114	14·38	2·087	14·20	2·061	14·03	2·037	13·86	2·013	13·70	1·990	13·54	1·967	13·38
3′ 2″ × 4′ 9″	2·257	17·10	2·227	16·87	2·198	16·65	2·170	16·44	2·143	16·24	2·116	16·05	2·091	15·86	2·067	15·67	2·044	15·49
3′ 4″ × 5′ 0″	2·340	19·64	2·309	19·38	2·279	19·13	2·250	18·89	2·222	18·66	2·195	18·44	2·169	18·22	2·144	18·01	2·120	17·81
3′ 6″ × 5′ 3″	2·421	22·42	2·389	22·12	2·358	21·83	2·329	21·56	2·300	21·30	2·272	21·04	2·245	20·79	2·219	20·55	2·194	20·32
3′ 8″ × 5′ 6″	2·501	25·41	2·468	25·08	2·436	24·76	2·405	24·44	2·376	24·14	2·348	23·85	2·321	23·57	2·294	23·30	2·268	23·04
3′ 10″ × 5′ 9″	2·580	28·65	2·546	28·28	2·513	27 91	2·481	27·56	2·451	27·22	2·422	26·89	2·393	26·58	2·365	26·27	2·339	25·98
4′ 0″ × 6′ 0″	2·657	32·14	2·622	31·71	2·588	31·30	2·556	30·91	2·524	30·53	2·494	30·16	2·465	29·81	2·436	29·47	2·409	29·14
4′ 2″ × 6′ 3″	2 733	35·87	2·698	35·39	2·663	34·93	2·629	34·49	2·597	34·07	2·566	33·67	2·536	33·28	2·507	32·90	2·479	32·53
4′ 4″ × 6′ 6″	2·808	39·86	2·771	39·33	2·736	38·82	2·702	38·33	2·669	37·86	2·636	37·41	2·605	36·98	2·575	36·55	2·547	36·14
4′ 6″ × 6′ 9″	2·882	44·11	2·843	43·53	2·806	42·97	2·771	42·44	2·738	41·92	2·706	41·41	2·674	40·93	2·643	40·46	2·614	40·00
4′ 8″ × 7′ 0″	2·954	48·63	2·915	4·799	2·878	47·37	2·843	46·78	2·808	46·21	2·774	45·66	2·742	45·13	2·710	44·62	2·680	42·12
4′ 10″ × 7′ 3″	3·026	53·44	2·986	52·73	2·949	52·05	2·912	51·40	2·876	50·78	2·841	50·17	2·808	49·58	2·777	49·01	2·746	48·47
5′ 0″ × 7′ 6″	3·097	58·52	3·056	57·76	3·017	57·02	2·980	56·31	2·943	55·62	2·908	54·95	2·874	54·31	2·841	53·69	2·809	53·09
5′ 2″ × 7′ 9″	3·167	63·86	3·125	63·02	3·085	62·22	3·047	61·45	3·009	60·71	2·974	59·99	2·939	59·29	2·905	58·62	2·873	57·97
5′ 4″ × 8′ 0″	3·235	69·56	3·193	68·64	3·152	67·76	3·113	66·92	3·075	66·10	3·038	65·31	3·002	64·55	2·968	63·82	2·935	63·11
5′ 6″ × 8′ 3″	3·303	75·53	3·260	74·55	3·219	73·59	3·178	72·67	3·139	71·78	3·102	70·92	3·066	70·09	3·031	69·29	2·997	68·52
5′ 8″ × 8′ 6″	3·371	81·81	3·327	80·74	3·284	79·71	3·243	78·71	3·203	77·75	3·165	76·83	3·129	75·93	3·094	75·08	3·059	74·23
5′ 10″ × 8′ 9″	3·436	88·39	3·391	87·24	3·348	86·12	3·307	85·04	3·267	84·00	3·228	83·00	3·190	82·04	3·154	81·10	3·119	80·19
6′ 0″ × 9′ 0″	3·502	95·30	3·456	94·04	3·412	92·84	3·370	91·68	3·329	90·57	3·290	89·50	3·252	88·47	3·215	87·47	3·179	86·50

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—)																	
	2350		2400		2450		2500		2550		2600		2650		2700		2750	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	·8561	·6470	·8464	·6397	·8371	·8327	·8280	·6258	·8192	·6191	·8106	·6126	·8023	·6063	·7942	·6002	·7863	·5943
1′ 2″ × 1′ 9″	·9649	·9922	·9541	·9813	·9436	·9707	·9334	·9603	·9234	·9501	·9138	·9402	·9045	·9306	·8954	·9212	·8866	·9121
1′ 4″ × 2′ 0″	1·069	1·436	1·057	1·420	1·046	1·405	1·034	1·390	1·023	1·375	1·012	1·361	1·002	1·347	·9924	1·333	·9826	1·320
1′ 6″ × 2′ 3″	1·169	1·987	1·156	1·965	1·144	1·944	1·132	1·924	1·120	1·904	1·108	1·884	1·096	1·865	1·085	1·846	1·075	1·823
1′ 8″ × 2′ 6″	1·265	2·657	1·251	2·627	1·238	2·598	1·225	2·570	1·212	2·543	1·199	2·517	1·186	2·492	1·175	2·468	1·164	2·444
1′ 10″ × 2′ 9″	1·359	3·452	1·344	3·414	1·329	3·377	1·315	3·341	1·301	3·306	1·288	3·272	1·277	3·239	1·264	3·208	1·252	3·177
2′ 0″ × 3′ 0″	1·450	4·382	1·434	4·334	1·418	4·287	1·403	4·242	1·388	4·198	1·374	4·155	1·360	4·113	1·347	4·072	1·335	4·033
2′ 2″ × 3′ 3″	1·537	5·455	1·520	5·395	1·504	5·337	1·488	5·281	1·472	5·226	1·457	5·173	1·443	5·121	1·429	5·071	1·416	5·023
2′ 4″ × 3′ 6″	1·623	6·679	1·605	6·606	1·588	6·535	1·571	6·466	1·555	6·399	1·539	6·334	1·524	6·271	1·509	6·209	1·495	6·149
2′ 6″ × 3′ 9″	1·707	8·061	1·688	7·973	1·670	7·888	1·652	7·805	1·635	7·724	1·618	7·645	1·602	8·569	1·586	7·495	1·571	7·423
2′ 8″ × 4′ 0″	1·788	9·610	1·768	9·505	1·749	9·404	1·731	9·305	1·713	9·209	1·696	9·116	1·679	9·026	1·663	8·938	1·647	8·852
2′ 10″ × 4′ 3″	1·867	11·33	1·847	11·20	1·827	11·08	1·808	10·97	1·789	10·86	1·771	10·75	1·754	10·64	1·737	10·54	1·720	10·44
3′ 0″ × 4′ 6″	1·945	13·23	1·924	13·09	1·904	12·95	1·884	12·81	1·864	12·68	1·846	12·55	1·828	12·43	1·810	12·31	1·793	12·19
3′ 2″ × 4′ 9″	2·022	15·32	2·000	15·16	1·979	15·00	1·958	14·84	1·938	14·69	1·919	14·54	1·900	14·40	1·881	14·26	1·863	14·12
3′ 4″ × 5′ 0″	2·096	17·61	2·074	17·42	2·052	17·23	2·031	17·05	2·010	16·87	1·990	16·70	1·970	16·54	1·951	16·38	1·932	16·23
3′ 6″ × 5′ 3″	2·170	20·09	2·147	19·87	2·124	19·66	2·102	19·46	2·080	19·26	2·059	19·06	2·039	18·87	2·019	18·69	2·000	18·52
3′ 8″ × 5′ 6″	2·243	22·78	2·218	22·53	2·194	22·30	2·171	22·07	2·149	21·84	2·128	21·62	2·107	21·41	2·087	21·20	2·067	21·00
3′ 10″ × 5′ 9″	2·313	25·69	2·288	25·42	2·264	25·15	2·241	24·89	2·218	24·63	2·196	24·38	2·174	24·14	2·153	23·91	2·132	23·69
4′ 0″ × 6′ 0″	2·383	28·81	2·357	28·50	2·332	28·20	2·309	27·91	2·285	27·63	2·261	27·35	2·240	27·08	2·219	26·82	2·198	26·57
4′ 2″ × 6′ 3″	2·451	32·17	2·425	31·82	2·399	31·49	2·374	31·16	2·350	30·84	2·327	30·54	2·304	30·24	2·282	29·95	2·261	29·67
4′ 4″ × 6′ 6″	2·519	35·75	2·492	35·36	2·465	34·98	2·440	34·62	2·415	34·27	2·391	33·93	2·368	33·60	2·345	33·28	2·323	32·97
4′ 6″ × 6′ 9″	2·585	39·57	2·557	39·15	2·530	38·74	2·504	38·33	2·479	37·94	2·455	37·56	2·431	37·19	2·407	36·84	2·384	36·50
4′ 8″ × 7′ 0″	2·651	43·63	2·622	43·16	2·595	42·71	2·568	42·27	2·542	41·84	2·517	41·43	2·492	41·02	2·468	40·63	2·445	40·25
4′ 10″ × 7′ 3″	2·715	47·94	2·686	47·42	2·658	46·92	2·631	46·44	2·604	45·97	2·578	45·52	2·554	45·08	2·528	44·65	2·505	44·23
5′ 0″ × 7′ 6″	2·779	52·50	2·749	51·94	2·720	51·40	2·692	50·88	2·665	50·36	2·638	49·86	2·613	49·38	2·588	48·91	2·564	48·45
5′ 2″ × 7′ 9″	2·842	57·34	2·812	56·73	2·783	56·13	2·754	55·55	2·726	54·98	2·699	54·43	2·673	53·90	2·647	53·39	2·622	52·90
5′ 4″ × 8′ 0″	2·903	62·41	2·872	61·74	2·842	61·10	2·813	60·48	2·785	59·88	2·758	59·29	2·731	58·71	2·705	58·15	2·680	57·61
5′ 6″ × 8′ 3″	2·965	67·78	2·934	67·06	2·903	66·37	2·873	65·69	2·844	65·03	2·816	64·39	2·789	63·77	2·763	63·16	2·737	62·57
5′ 8″ × 8′ 6″	3·025	73·42	2·993	72·64	2·962	71·88	2·932	71·15	2·902	70·44	2·873	69·74	2·845	69·07	2·818	68·42	2·793	67·78
5′ 10″ × 8′ 9″	3·085	79·30	3·052	78·44	3·020	77·61	2·989	76·90	2·959	76·12	2·930	75·36	2·902	74·63	2·874	73·92	2·847	73·23
6′ 0″ × 9′ 0″	3·144	85·56	3·110	84·65	3·078	83·76	3·047	82·90	3·016	82·07	2·986	81·26	2·957	80·48	2·929	79·72	2·902	79·98

TABLE 57 (Continued).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

Egg-Shaped Sewers.—Running Two-thirds Full. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—) 2800		2850		2900		2950		3000		3050		3100		3150		3200	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 0″ × 1′ 6″	·7786	·5885	·7711	·5828	·7638	·5773	·7568	·5720	·7499	·5668								
1′ 2″ × 1′ 9″	·8781	·9033	·8697	·8947	·8615	·8863	·8536	·8781	·8458	·8701	·8383	·8623	·8309	·8547	·8237	·8473	·8166	·8401
1′ 4″ × 2′ 0″	·9732	1·307	·9641	1·295	·9551	1·283	·9463	1·271	·9377	1·260	·9293	1·249	·9212	1·238	·9133	1·227	·9055	1·216
1′ 6″ × 2′ 3″	1·065	1·811	1·055	1·794	1·045	1·777	1·035	1·761	1·026	1·745	1·017	1·729	1·008	1·714	·9994	1·700	·9910	1·685
1′ 8″ × 2′ 6″	1·153	2·421	1·142	2·398	1·132	2·376	1·122	2·355	1·112	2·334	1·102	2·313	1·092	2·293	1·083	2·273	1·074	2·254
1′ 10″ × 2′ 9″	1·239	3·147	1·227	3·117	1·216	3·008	1·205	3·060	1·194	3·033	1·183	3·007	1·173	2·981	1·163	2·955	1·153	2·930
2′ 0″ × 3′ 0″	1·322	3·995	1·309	3·958	1·297	3·922	1·285	3·887	1·274	3·852	1·263	3·818	1·252	3·784	1·241	3·751	1·231	3·719
2′ 2″ × 3′ 3″	1·402	4·975	1·389	4·928	1·376	4·883	1·364	4·839	1·352	4·796	1·340	4·754	1·328	4·713	1·317	4·673	1·306	4·634
2′ 4″ × 3′ 6″	1·481	6·091	1·467	6·035	1·453	5·980	1·440	5·926	1·427	5·874	1·415	5·823	1·403	5·773	1·391	5·724	1·379	5·676
2′ 6″ × 3′ 9″	1·557	7·353	1·543	7·285	1·529	7·219	1·515	7·155	1·501	7·092	1·488	7·030	1·475	6·970	1·463	6·911	1·451	6·854
2′ 8″ × 4′ 0″	1·631	8·769	1·616	8·688	1·601	8·609	1·587	8·532	1·573	8·457	1·560	8·383	1·547	8·312	1·534	8·242	1·521	8·174
2′ 10″ × 4′ 3″	1·704	10·34	1·689	10·24	1·674	10·15	1·659	10·06	1·646	9·974	1·630	9·888	1·616	9·804	1·602	9·722	1·589	9·642
3′ 0″ × 4′ 6″	1·776	12·08	1·760	11·97	1·744	11·86	1·728	11·75	1·713	11·65	1·698	11·55	1·684	11·45	1·670	11·35	1·656	11·26
3′ 2″ × 4′ 9″	1·846	13·99	1·829	13·86	1·813	13·74	1·797	13·62	1·781	13·50	1·765	13·38	1·750	13·27	1·736	13·16	1·722	13·05
3′ 4″ × 5′ 0″	1·914	16·08	1·897	15·93	1·880	15·79	1·863	15·65	1·847	15·51	1·831	15·38	1·816	15·25	1·801	15·12	1·786	15·00
3′ 6″ × 5′ 3″	1·982	18·35	1·964	18·18	1·946	18·02	1·929	17·86	1·912	17·70	1·896	17·55	1·880	17·40	1·864	17·26	1·849	17·12
3′ 8″ × 5′ 6″	2·048	20·81	2·029	20·62	2·011	20·44	1·993	20·26	1·976	20·08	1·959	19·91	1·942	19·74	1·926	19·57	1·910	19·41
3′ 10″ × 5′ 9″	2·112	23·47	2·094	23·26	2·075	23·05	2·057	22·85	2·039	22·65	2·022	22·45	2·005	22·26	1·988	22·08	1·972	21·90
4′ 0″ × 6′ 0″	2·177	26·33	2·157	26·09	2·138	25·85	2·119	25·62	2·101	25·40	2·083	25·19	2·065	24·98	2·048	24·77	2·031	24·57
4′ 2″ × 6′ 3″	2·240	29·40	2·220	29·13	2·220	28·87	2·180	28·61	2·161	28·36	2·143	28·12	2·125	27·88	2·108	27·65	2·091	27·43
4′ 4″ × 6′ 6″	2·302	32·67	2·281	32·37	2·261	32·08	2·241	31·80	2·221	31·53	2·220	31·26	2·184	31·00	2·166	30·74	2·148	30·49
4′ 6″ × 6′ 9″	2·363	36·17	2·342	35·84	2·321	35·52	2·300	35·21	2·280	34·90	2·261	34·60	2·242	34·31	2·224	34·03	2·206	33·76
4′ 8″ × 7′ 0″	2·423	39·88	2·401	39·52	2·380	39·17	2·359	38·83	2·338	38·50	2·318	38·17	2·299	37·85	2·280	37·54	2·262	37·24
4′ 10″ × 7′ 3″	2·482	43·82	2·460	43·42	2·438	43·04	2·417	42·67	2·396	42·30	2·375	41·94	2·355	41·59	2·336	41·25	2·317	40·92
5′ 0″ × 7′ 6″	2·541	48·01	2·518	47·58	2·496	47·16	2·474	46·75	2·453	46·35	2·432	45·96	2·412	45·58	2·392	45·20	2·372	44·83
5′ 2″ × 7′ 9″	2·598	52·42	2·575	51·95	2·552	51·49	2·530	51·04	2·508	50·60	2·487	50·17	2·466	49·75	2·446	49·35	2·426	48·96
5′ 4″ × 8′ 0″	2·655	57·08	2·631	56·57	2·608	56·07	2·585	55·58	2·563	55·10	2·541	54·64	2·520	54·19	2·599	53·75	2·479	53·32
5′ 6″ × 8′ 3″	2·712	62·00	2·687	61·44	5·663	60·90	2·640	60·37	2·618	59·85	2·596	59·34	2·574	58·85	2·553	58·37	2·533	57·90
5′ 8″ × 8′ 6″	2·768	67·16	2·744	66·56	2·718	65·98	2·695	65·41	2·672	64·84	2·649	64·29	2·627	63·76	2·606	63·24	2·585	62·73
5′ 10″ × 8′ 9″	2·822	72·56	2·797	71·91	2·772	71·28	2·748	70·67	2·724	70·07	2·701	69·48	2·679	68·90	2·657	68·34	2·636	67·79
6′ 0″ × 9′ 0″	2·876	78·26	2·851	77·56	2·826	76·88	2·801	76·21	2·777	75·56	2·754	74·92	2·731	74·30	2·709	73·69	2·687	73·10

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—)																	
	3250		3300		3350		3400		3450		3500		3550		3600		3650	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 2″ × 1′ 9″	·8097	·8330	·8030	·8260	·7964	·8193	·7900	·8126	·7837	·8061	·7775	·7998	·7714	·7936	·7655	·7875	·7597	·7815
1′ 4″ × 2′ 0″	·8979	1·206	·8905	1·196	·8832	1·186	·8761	1·177	·8691	1·168	·8623	1·159	·8557	1·150	·8491	1·141	·8427	1·132
1′ 6″ × 2′ 3″	·9827	1·671	·9746	1·657	·9667	1·644	·9589	1·631	·9513	1·618	·9439	1·605	·9367	1·593	·9296	1·581	·9226	1·569
1′ 8″ × 2′ 6″	·1065	2·235	1·056	2·217	1·047	2·199	1·039	2·181	1·031	2·164	1·023	2·147	1·015	2·131	1·007	2·115	·9999	2·099
1′ 10″ × 2′ 9″	1·143	2·906	1·134	2·882	1·125	2·859	1·116	2·836	1·107	2·814	1·099	2·792	1·091	2·771	1·083	2·750	1·075	2·730
2′ 0″ × 3′ 0″	1·221	3·688	1·211	3·658	1·201	3·629	1·192	3·601	1·183	3·574	1·174	3·547	1·165	3·520	1·156	3·493	1·147	3·467
2′ 2″ × 3′ 3″	1·295	4·596	1·285	4·559	1·275	4·523	1·265	4·487	1·255	4·452	1·245	4·418	1·236	4·385	1·227	4·352	1·218	4·320
2′ 4″ × 3′ 6″	1·368	5·630	1·357	5·584	1·346	5·540	1·335	5·496	1·325	5·453	1·315	5·412	1·305	5·371	1·295	5·331	1·286	5·292
2′ 6″ × 3′ 9″	1·439	6·798	1·427	6·743	1·416	6·689	1·405	6·637	1·394	6·586	1·383	6·535	1·373	6·486	1·363	6·438	1·353	6·391
2′ 8″ × 4′ 0″	1·508	8·107	1·496	8·042	1·484	7·978	1·473	7·916	1·462	7·855	1·451	7·795	1·440	7·737	1·429	7·680	1·418	7·624
2′ 10″ × 4′ 3″	1·576	9·563	1·563	9·486	1·551	9·412	1·539	9·339	1·527	9·267	1·515	9·196	1·504	9·127	1·493	9·060	1·482	8·994
3′ 0″ × 4′ 6″	1·643	11·17	1·630	11·08	1·617	10·99	1·604	10·91	1·592	10·83	1·580	10·75	1·568	10·67	1·556	10·59	1·545	10·51
3′ 2″ × 4′ 9″	1·708	12·94	1·694	12·84	1·681	12·74	1·668	12·64	1·655	12·54	1·642	12·45	1·630	12·36	1·618	12·27	1·606	12·18
3′ 4″ × 5′ 0″	1·771	14·88	1·757	14·76	1·743	14·64	1·730	14·53	1·717	14·42	1·704	14·31	1·691	14·20	1·679	14·10	1·667	14·00
3′ 6″ × 5′ 3″	1·834	16·98	1·819	16·84	1·805	16·71	1·791	16·58	1·777	16·46	1·764	16·33	1·751	16·21	1·738	16·09	1·726	15·98
3′ 8″ × 5′ 6″	1·895	19·26	1·880	19·11	1·865	18·96	1·851	18·81	1·837	18·67	1·823	18·53	1·810	18·39	1·797	18·26	1·784	18·13
3′ 10″ × 5′ 9″	1·956	21·72	1·941	21·55	1·926	21·38	1·911	21·22	1·896	21·06	1·882	20·90	1·868	20·75	1·854	20·60	1·841	20·45
4′ 0″ × 6′ 0″	2·015	24·37	1·999	24·18	1·984	23·99	1·969	23·81	1·954	23·63	1·939	23·45	1·924	23·28	1·910	23·11	1·897	22·94
4′ 2″ × 6′ 3″	2·074	27·21	2·057	27·00	2·041	26·79	2·026	26·58	2·011	26·38	1·996	26·18	1·981	25·99	1·966	25·80	1·952	25·62
4′ 4″ × 6′ 6″	2·131	30·25	2·114	30·01	2·098	29·78	2·082	29·55	2·066	29·33	2·051	29·11	2·036	28·89	2·021	28·68	2·007	28·48
4′ 6″ × 6′ 9″	2·188	33·49	2·171	33·23	2·154	32·97	2·138	32·72	2·122	32·47	2·106	32·23	2·090	31·99	2·075	31·76	2·060	31·54
4′ 8″ × 7′ 0″	2·244	36·94	2·226	36·65	2·209	36·36	2·192	36·08	2·176	35·81	2·160	35·55	2·144	35·29	2·128	35·04	2·113	34·79
4′ 10″ × 7′ 3″	2·299	40·59	2·281	40·27	2·263	39·96	2·246	39·66	2·229	39·36	2·213	39·07	2·197	38·79	2·181	38·51	2·165	38·23
5′ 0″ × 7′ 6″	2·353	44·47	2·335	44·12	2·317	43·78	2·299	43·45	2·282	43·13	2·265	42·81	2·249	42·50	2·233	42·19	2·217	41·89
5′ 2″ × 7′ 9″	2·407	48·57	2·388	48·19	2·370	47·82	2·352	47·46	2·334	47·10	2·317	46·75	2·300	46·41	2·284	46·08	2·268	45·75
5′ 4″ × 8′ 0″	2·460	52·89	2·441	52·47	2·422	52·06	2·404	51·67	2·386	51·29	2·368	50·91	2·351	50·54	2·334	50·18	2·317	49·83
5′ 6″ × 8′ 3″	2·513	57·44	2·493	56·99	2·474	56·55	2·455	56·13	2·437	55·71	2·419	55·30	2·401	54·89	2·384	54·50	2·367	54·12
5′ 8″ × 8′ 6″	2·564	62·23	2·544	61·75	2·525	61·28	2·506	60·82	2·487	60·37	2·469	59·92	2·451	59·48	2·433	59·05	2·416	58·63
5′ 10″ × 8′ 9″	2·615	67·26	2·595	66·74	2·575	66·23	2·556	65·73	2·537	65·24	2·518	64·76	2·500	64·29	2·482	63·83	2·464	63·38
6′ 0″ × 9′ 0″	2·666	72·53	2·645	71·97	2·625	71·42	2·605	70·88	2·586	70·35	2·567	69·83	2·548	69·33	2·530	68·84	2·512	68·35

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where n = ·015.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—)																	
	3700		3750		3800		3850		3900		3950		4000		4200		4400	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 2″ × 1′ 9″	·7540	·7757																
1′ 4″ × 2′ 0″	·8365	1·124	·8303	1·116	·8243	1·108	·8184	1·100	·8126	1·092	·8069	1·084	·8013	1·077	·7800	1·048	·7602	1·021
1′ 6″ × 2′ 3″	·9158	1·557	·9091	1·546	·9025	1·535	·8961	1·524	·8898	1·513	·8836	1·503	·8775	1·492	·8543	1·453	·8326	1·416
1′ 8″ × 2′ 6″	·9925	2·084	·9853	2·060	·9782	2·064	·9713	2·039	·9645	2·025	·9578	2·011	·9513	1·997	·9262	1·944	·9028	1·895
1′ 10″ × 2′ 9″	1·067	2·710	1·059	2·690	1·051	2·671	1·044	2·652	1·037	2·633	1·030	2·615	1·023	2·597	·9957	2·529	·9707	2·466
2′ 0″ × 3′ 0″	1·138	3·442	1·130	3·417	1·122	1·393	1·114	3·369	1·106	3·346	1·099	3·323	1·092	3·300	1·064	3·214	1·037	3·134
2′ 2″ × 3′ 3″	1·209	4·288	1·200	4·257	1·191	4·227	1·183	4·198	1·175	4·169	1·167	4·140	1·159	4·112	1·129	4·005	1·101	3·905
2′ 4″ × 3′ 6″	1·227	5·254	1·268	5·216	1·259	5·179	1·250	5·143	1·241	5·108	1·233	5·073	1·225	5·039	1·193	4·908	1·163	4·786
2′ 6″ × 3′ 9″	1·343	6·345	1·333	6·300	1·324	6·255	1·315	6·212	1·306	6·169	1·297	6·127	1·288	6·085	1·255	5·929	1·224	5·783
2′ 8″ × 4′ 0″	1·408	7·569	1·398	7·515	1·388	7·462	1·378	7·410	1·369	7·359	1·360	7·310	1·351	7·261	1·316	7·074	1·283	6·900
2′ 10″ × 4′ 3″	1·471	8·930	1·461	8·867	1·451	8·805	1·441	8·744	1·431	8·684	1·421	8·625	1·412	8·567	1·376	8·352	1·342	8·143
3′ 0″ × 4′ 6″	1·534	10·43	1·523	10·36	1·512	10·29	1·502	10·22	1·492	10·15	1·482	10·08	1·472	10·01	1·434	9·757	1·399	9·518
3′ 2″ × 4′ 9″	1·595	12·09	1·584	12·00	1·573	11·92	1·562	11·84	1·551	11·76	1·541	11·68·	1·531	11·60	1·492	11·31	1·455	11·03
3′ 4″ × 5′ 0″	1·655	13·90	1·643	13·80	1·632	13·70	1·621	13·61	1·610	13·52	1·599	13·43	1·588	13·34	1·548	13·00	1·510	12·69
3′ 6″ × 5′ 3″	1·714	15·86	1·702	15·75	1·690	15·64	1·678	15·53	1·667	15·43	1·656	15·33	1·645	15·23	1·603	14·84	1·564	14·48
3′ 8″ × 5′ 6″	1·771	18·00	1·759	17·87	1·747	17·75	1·735	17·63	1·723	17·51	1·711	17·39	1·700	17·27	1·657	16·83	1·617	16·43
3′ 10″ × 5′ 9″	1·828	20·30	1·815	20·16	1·803	20·02	1·791	19·88	1·779	19·74	1·767	19·60	1·755	19·49	1·711	19·00	1·669	18·54
4′ 0″ × 6′ 0″	1·884	22·78	1·871	22·62	1·858	22·47	1·845	22·31	1·833	22·16	1·821	22·02	1·809	21·87	1·763	21·32	1·720	20·81
4′ 2″ × 6′ 3″	1·938	25·44	1·925	25·26	1·912	25·09	1·899	24·92	1·886	24·75	1·873	24·58	1·861	24·42	1·814	23·81	1·770	23·24
4′ 4″ × 6′ 6″	1·993	28·28	1·979	28·08	1·965	27·89	1·952	27·70	1·939	27·52	1·926	27·34	1·913	27·16	1·865	26·48	1·821	25·84
4′ 6″ × 6′ 9″	2·046	31·32	2·032	31·10	2·018	30·88	2·004	30·67	1·991	30·47	1·978	30·27	1·965	30·07	1·917	29·33	1·871	28·64
4′ 8″ × 7′ 0″	2·098	34·54	2·084	34·30	2·070	34·07	2·056	33·84	2·042	33·61	2·028	33·39	2·015	33·17	1·965	32·34	1·918	31·57
4′ 10″ × 7′ 3″	2·150	37·96	2·135	37·70	2·120	37·44	2·106	37·19	2·092	36·94	2·078	36·70	2·065	36·46	2·013	35·55	1·965	34·70
5′ 0″ × 7′ 6″	2·201	41·60	2·186	41·31	2·171	41·03	2·156	40·75	2·142	40·48	2·128	40·21	2·114	39·95	2·062	38·96	2·013	38·03
5′ 2″ × 7′ 9″	2·252	45·43	2·236	45·12	2·221	44·81	2·206	44·51	2·191	44·21	2·177	43·92	2·163	43·64	2·109	42·55	2·059	41·54
5′ 4″ × 8′ 0″	2·301	49·48	2·285	49·14	2·270	48·80	2·255	48·47	2·240	48·15	2·225	47·84	2·211	47·53	2·156	46·35	2·105	45·25
5′ 6″ × 8′ 3″	2·351	53·74	2·335	53·37	2·319	53·01	2·303	52·66	2·288	52·31	2·273	51·97	2·258	51·63	2·202	50·35	2·150	49·16
5′ 8″ × 8′ 6″	2·399	58·22	2·383	57·82	2·367	57·43	2·351	57·05	2·335	56·68	2·320	56·31	2·305	55·94	2·248	54·56	2·195	53·26
5′ 10″ × 8′ 9″	2·447	62·94	2·430	62·51	2·414	62·09	2·398	61·67	2·382	61·26	2·367	60·86	2·351	60·47	2·293	58·97	2·239	57·58
6′ 0″ × 9′ 0″	2·495	67·87	2·478	67·41	2·461	66·96	2·444	66·51	2·428	66·07	2·412	65·64	2·397	65·22	23·38	63·61	2·283	62·11

TABLE 57 (CONTINUED).—VELOCITY AND DISCHARGE CALCULATED BY GANGUILLET AND KUTTER'S FORMULA.

EGG-SHAPED SEWERS.—RUNNING TWO-THIRDS FULL. (Where $n = \cdot 015$.)

V = Velocity of Discharge in feet per Second. Q = Discharge in Cubic feet per Second.

Size.	Sine of Inclination. (1 over:—)																	
	4600		4800		5000		5250		5500		5750		6000		6500		7000	
	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.	V.	Q.
1′ 4″ × 2′ 0″	·7415	·9963	·7240	·9729	·7076	·9508	·6885	·9250	·6706	·9010	·6539	·8786	·6382	·8575	·6095	·8190	·5840	·7846
1′ 6″ × 2′ 3″	·8124	1·381	·7934	1·349	·7756	1·319	·7546	1·283	·7351	1·250	·7170	1·219	·6999	1·190	·6686	1·137	·6409	1·090
1′ 8″ × 2′ 6″	·8810	1·850	·8605	1·807	·8413	1·766	·8187	1·719	·7977	1·675	·7781	1·634	·7595	1·594	·7261	1·524	·6961	1·461
1′ 10″ × 2′ 9″	·9474	2·407	·9254	2·351	·9049	2·299	·8807	2·237	·8583	2·180	·8373	2·127	·8176	2·007	·7816	1·985	·7495	1·904
2′ 0″ × 3′ 0″	1·012	3·095	·9885	2·988	·9665	2·921	·9410	2·845	·9171	2·773	·8947	2·705	·8738	2·641	·8356	2·526	·8010	2·422
2′ 2″ × 3′ 3″	1·975	3·812	1·050	3·725	1·027	3·643	·9996	3·547	·9744	3·457	·9507	3·373	·9286	3·295	·8882	3·151	·8521	3·023
2′ 4″ × 3′ 6″	1·135	4·672	1·109	4·566	1·085	4·466	1·057	4·349	1·030	4·239	1·005	4·136	·9820	4·040	·9395	3·866	·9016	3·709
2′ 6″ × 3′ 9″	1·195	5·646	1·168	5·517	1·143	5·397	1·113	5·255	1·085	5·124	1·059	5·001	1·034	4·885	·9896	4·675	·9499	4·487
2′ 8″ × 4′ 0″	1·253	6·737	1·225	6·584	1·198	6·441	1·167	6·273	1·138	6·116	1·111	5·970	1·085	5·833	1·039	5·582	·9971	5·359
2′ 10″ × 4′ 3″	1·311	7·951	1·281	7·772	1·253	7·603	1·221	7·405	1·190	7·221	1·162	7·049	1·135	6·888	1·087	6·593	1·043	6·331
3′ 0″ × 4′ 6″	1·366	9·294	1·336	9·085	1·307	8·890	1·272	8·659	1·241	8·444	1·212	8·244	1·184	8·056	1·134	7·713	1·089	7·406
3′ 2″ × 4′ 9″	1·421	10·77	1·389	10·53	1·359	10·30	1·324	10·03	1·292	9·788	1·261	9·557	1·232	9·340	1·180	8·943	1·133	8·589
3′ 4″ × 5′ 0″	1·475	12·39	1·442	12·11	1·411	11·85	1·375	11·54	1·341	11·26	1·309	10·99	1·280	10·74	1·225	10·29	1·177	9·885
3′ 6″ × 5′ 3″	1·528	14·14	1·494	13·83	1·462	13·53	1·424	13·19	1·389	12·86	1·356	12·56	1·326	12·28	1·270	11·76	1·220	11·30
3′ 8″ × 5′ 6″	1·580	16·06	1·545	15·71	1·512	15·36	1·473	14·96	1·437	14·60	1·403	14·27	1·371	13·94	1·314	13·36	1·265	12·86
3′ 10′ × 5′ 9″	1·631	18·11	1·594	17·71	1·560	17·33	1·521	16·89	1·484	16·48	1·449	16·09	1·417	15·73	1·357	15·07	1·304	14·48
4′ 0″ × 6′ 0″	1·681	20·33	1·644	19·88	1·609	19·45	1·568	18·96	1·530	18·50	1·494	18·07	1·460	17·66	1·399	16·92	1·345	16·26
4′ 2″ × 6′ 3″	1·730	22·70	1·691	22·20	1·655	21·73	1·614	21·18	1·575	20·66	1·538	20·18	1·504	19·74	1·441	18·91	1·385	18·17
4′ 4″ × 6′ 6″	1·779	25·24	1·739	24·68	1·702	24·16	1·659	23·55	1·619	22·98	1·582	22·45	1·546	21·95	1·482	21·04	1·425	20·22
4′ 6″ × 6′ 9″	1·827	27·98	1·787	27·35	1·749	26·75	1·704	26·09	1·663	25·47	1·625	24·88	1·589	24·32	1·523	23·31	1·464	22·41
4′ 8″ × 7′ 0″	1·874	30·84	1·833	30·17	1·794	29·53	1·749	28·79	1·707	28·09	1·667	27·44	1·630	26·83	1·563	25·73	1·503	24·74
4′ 10″ × 7′ 3″	1·920	33·91	1·878	33·17	1·839	32·47	1·793	31·65	1·750	30·89	1·709	30·18	1·671	29·51	1·602	28·29	1·541	27·20
5′ 0″ × 7′ 6″	1·967	37·16	1·924	36·35	1·883	35·58	1·836	34·69	1·792	33·85	1·751	33·07	1·712	32·35	1·641	31·02	1·579	29·83
5′ 2″ × 7′ 9″	2·012	40·59	1·968	39·71	1·926	38·87	1·878	37·90	1·834	37·03	1·792	36·15	1·752	35·35	1·680	33·89	1·616	32·60
5′ 4″ × 8′ 0″	2·087	44·22	2·012	43·26	1·969	42·36	1·920	41·29	1·874	40·30	1·831	39·38	1·791	38·51	1·718	36·93	1·652	35·52
5′ 6″ × 8′ 3″	2·101	48·04	2·055	46·99	2·012	46·01	1·962	44·86	1·915	43·79	1·871	42·79	1·831	41·85	1·756	40·14	1·689	38·61
5′ 8″ × 8′ 6″	2·145	52·06	2·098	50·92	2·054	49·86	2·003	48·62	1·956	47·46	1·912	46·38	1·869	45·36	1·793	43·51	1·725	41·86
5′ 10″ × 8′ 9″	2·188	56·28	2·141	55·05	2·096	53·91	2·044	52·56	1·996	51·31	1·951	50·14	1·907	49·05	1·829	47·05	1·760	45·27
6′ 0″ × 9′ 0″	2·232	60·71	2·183	59·39	2·137	58·15	2·084	56·70	2·035	55·36	1·989	54·10	1·945	52·92	1·866	50·77	1·795	48·84

TABLE 58.—VELOCITY AND DISCHARGE OF EGG-SHAPED SEWERS, CALCULATED BY FLYNN'S MODIFICATION OF KUTTER'S FORMULA, FOR VARIOUS DEPTHS ON THE INVERT (WHERE n = ·013).

v = MEAN VELOCITY IN FEET PER SECOND.

Q = DISCHARGE IN CUBIC FEET PER SECOND.

Slope 1 in	Full Depth.		Two-thirds Full Depth.		One-third Full Depth.	
	v	Q	v	Q	v	Q
	Size of Sewer 2′ 9″ × 3′ 0″					
100	7·94	36·48	8·46	25·57	6·21	7·06
200	5·61	25·8	5·98	18·08	4·39	4·99
300	4·58	21·06	4·88	14·76	3·59	4·07
500	3·55	16·31	3·78	11·43	2·78	3·16
700	3·	13·79	3·2	9·66	2·35	2·67
1000	2·51	11·54	2·67	8·08	1·96	2·23
1200	2·29	10·53	2·44	7·38	1·79	2·04
1500	2·05	9·92	2·18	6·6	1·6	1·82
	Size of Sewer 2′ 2″ × 3′ 3″					
100	8·41	45·35	8·94	31·72	6·59	8·78
200	5·95	32·07	6·32	22·43	4·66	6·21
300	4·85	26·19	5·16	18·31	3·80	5·07
500	4·01	21·64	4·26	15·14	3·14	4·19
700	3·18	17·14	3·38	11·99	2·49	3·32
1000	2·66	14·34	2·83	10·03	2·08	2·78
1200	2·43	13·09	2·58	9·15	1·9	2·53
1500	2·17	12·71	2·31	8·19	1·7	2·26
	Size of Sewer 2′ 4″ × 3′ 6″					
150	7·24	45·26	7·68	31·63	5·69	8·8
300	5·12	32·	5·43	22·37	4·02	6·22
600	3·62	22·63	3·84	15·81	2·84	4·4
1000	2·8	17·53	2·97	12·25	2·2	3·41
1250	2·51	15·68	2·66	10·96	1·97	3·05
1500	2·29	14·31	2·43	10·	1·8	2·78
1750	2·12	13·25	2·25	9·26	1·67	2·58
2000	1·98	12·39	2·1	8·66	1·56	2·41
	Size of Sewer 2′ 6″ × 3′ 9″					
300	5·37	38·57	5·71	26·99	4·2	7·5
600	3·8	27·27	4·04	19·08	2·98	5·31
1000	2·94	21·12	3·13	14·78	2·31	4·11
1250	2·63	18·89	2·8	13·22	2·06	3·68
1500	2·4	17·25	2·55	12·07	1·88	3·36
1750	2·22	15·97	2·37	11·17	1·74	3·11
2000	2·08	14·94	2·21	10·45	1·63	2·91
2640	1·81	13·	1·93	9·1	1·42	2·53
	Size of Sewer 2′ 8″ × 4′ 0″					
500	4·35	35·57	4·62	24·87	3·42	6·91
750	3·55	29·04	3·77	20·30	2·79	5·64
1000	3·08	25·15	3·27	17·58	2·42	4·89
1250	2·75	22·49	2·92	15·73	2·16	4·37
1500	2·51	20·53	2·67	14·36	1·97	3·99
1750	2·32	19·01	2·47	13·29	1·83	3·69
2000	2·17	17·78	2·31	12·43	1·71	3·45
2640	1·89	15·48	2·01	10·82	1·49	3·01

TABLE 58—*continued.*

Slope 1 in	Full Depth.		Two-thirds Full Depth.		One-third Full Depth.	
	v	Q	*v*	Q	*v*	Q
	Size of Sewer 2′ 10″ × 4′ 3″					
500	4·54	41·90	4·82	29·26	3·57	8·15
750	3·70	34·21	3·93	23·89	2·92	6·66
1000	3·21	29·63	3·41	20·69	2·52	5·76
1250	3·87	26·50	3·05	18·50	2·26	5·15
1500	2·62	24·19	2·78	16·89	2·06	4·70
1750	2·42	22·39	2·57	15·64	1·91	4·36
2000	2·27	20·95	2·41	14·63	1·78	4·07
2640	1·97	18·23	2·10	12·73	1·55	3·55
	Size of Sewer 3′ 0″ × 4′ 6″					
500	4·72	48·83	5·01	34·11	3·73	9·54
750	3·85	39·87	4·09	27·85	3·04	7·79
1000	3·33	34·53	3·54	24·12	2·64	6·74
1250	2·98	30·88	3·17	21·57	2·36	6·03
1500	2·72	28·19	2·89	19·69	2·15	5·50
1750	2·52	26·10	2·67	18·23	1·99	5·10
2000	2·36	24·41	2·50	17·05	1·86	4·77
2640	2·05	21·25	2·18	14·84	1·62	4·15
	Size of Sewer 3′ 2″ × 4′ 9″					
500	4·90	56·52	5·20	39·48	3·87	11·04
750	4·	46·15	4·25	32·24	3·16	9·01
1000	3·46	39·97	3·68	27·92	2·74	7·80
1250	3·10	35·75	3·29	24·97	2·45	6·98
1500	2.83	32·63	3·	22·79	2·23	6·37
1750	2·62	30·21	2·78	21·10	2·07	5·90
2000	2·45	28·26	2·60	19·74	1·93	5·52
2640	2·13	24·60	2·26	17·18	1·68	4·80
	Size of Sewer 3′ 4″ × 5′ 0″					
500	5·08	64·89	5·39	45·25	4·01	12·67
750	4·15	52·98	4·40	36·95	3·27	10·35
1000	3·59	45·88	3·81	32·	2·83	8·96
1250	3·21	41·	3·41	28·62	2·53	8·01
1500	2·93	37·46	3·11	26·13	2·32	7·32
1750	2·72	34·68	2·88	24·19	2·14	6·77
2000	2·54	32·44	2·69	22·63	2·01	6·34
2640	2·21	28·24	2·34	19·69	1·74	5·51
	Size of Sewer 3′ 6″ × 5′ 3″					
500	5·26	73·97	5·57	51·56	4·15	14·45
750	4·29	60·39	4·55	42·10	3·39	11·80
1000	3·72	52·30	3·94	36·46	2·94	10·22
1250	3·32	46·78	3·52	32·61	2·62	9·14
1500	3·03	42·70	3·21	29·77	2·40	8·34
1750	2·81	39·53	2·98	27·56	2·22	7·72
2000	2·63	36·98	2·78	25·78	2·08	7·22
2640	2·29	32·19	2·42	22·44	1·81	6·29
	Size of Sewer 3′ 8″ × 5′ 6″					
500	5·43	83·81	5·75	58·45	4·29	16·39
750	4·43	68·43	4·69	47·72	3·50	13·38
1000	3·84	59·26	4·07	41·33	3·03	11·59
1250	3·43	53·	3·64	36·97	2·71	10·37
1500	3·13	43·39	3·32	33·74	2·48	9·46
1750	2·9	44·8	3·07	31·24	2·29	8·76
2000	2·71	41·9	2·87	29·22	2·14	8·19
2640	2·36	36·47	2·50	25·44	1·87	7·13

TABLE 58—*continued.*

Slope 1 in	Full Depth.		Two-thirds Full Depth.		One-third Full Depth.	
	v	Q	*v*	Q	*v*	Q
	Size of Sewer 3′ 10″ × 5′ 9″					
750	4·56	77·08	4·84	53·75	3·62	15·11
1000	3·95	66·76	4·19	46·55	3·13	13·08
1250	3·53	59·71	4·03	41·63	2·8	11·7
1500	3·23	54·51	3·42	38·	2·56	10·68
1750	2·99	50·46	3·17	35·19	2·37	9·89
2000	2·79	47·2	2·96	32·91	2·22	9·25
2640	2·43	41·09	2·58	28·65	1·93	8·05
3000	2·28	38·54	2·42	26·87	1·81	7·55
	Size of Sewer 4′ 0″ × 6′ 0″					
1000	4·07	74·82	4·31	52·14	3·22	14·66
1250	3·64	66·91	3·85	46·64	2·88	13·12
1500	3·32	61·09	3·52	42·57	2·63	11·97
1750	3·07	56·66	3·26	39·41	2·44	11·08
2000	2·88	52·90	3·05	36·87	2·28	10·37
2640	2·50	46·04	2·65	32·09	1·98	9·02
3000	2·35	43·19	2·49	30·10	1·86	8·46
3500	2·17	39·99	2·30	27·87	1·72	7·84
	Size of Sewer 4′ 2″ × 6′ 3″					
1000	4·18	83·48	4·43	58·12	3·32	16·37
1250	3·74	74·66	3·96	51·98	2·96	14·64
1500	3·41	68·16	3·61	47·45	2·71	13·37
1750	3·16	63·10	3·34	43·93	2·51	12·38
2000	2·96	59·03	3·13	41·09	2·34	11·58
2640	2·57	51·38	2·72	35·77	2·04	10·07
3000	2·41	48·19	2·55	33·55	1·91	9·45
3500	2·29	44·62	2·36	31·06	1·77	8·75
	Size of Sewer 4′ 4″ × 6′ 6″					
1250	3·84	82·79	4·07	57·73	3·05	16·27
1500	3·5	75·57	3·71	52·7	2·78	14·85
1750	3·24	69·97	3·44	48·79	2·58	13·45
2000	3·03	65·45	3·21	45·64	2·41	12·86
2640	2·64	56·97	2·8	39·72	2·1	11·19
3000	2·48	53·44	2·62	37·26	1·97	10·5
3500	2·29	49·47	2·43	34·5	1·82	9·72
4000	2·14	46·28	2·27	32·27	1·7	9·09
	Size of Sewer 4′ 6″ × 6′ 9″					
1250	3·94	91·61	4·17	63·84	3·13	18·01
1500	3·6	83·63	3·81	58·27	2·85	16·44
1750	3·33	43·43	3·52	53·95	2·65	15·22
2000	3·11	42·42	3·3	50·47	2·47	14·24
2640	2·71	04·04	2·87	43·93	2·15	12·39
3000	2·54	13·13	2·69	41·21	2·02	11·62
3500	2·35	75·75	2·49	38·15	1·87	10·76
4000	2·2	21·21	2·33	35·68	1·75	10·07

TABLE 58—*continued.*

Slope 1 in	Full Depth. *v*	Full Depth. Q	Two-thirds Full Depth. *v*	Two-thirds Full Depth. Q	One-third Full Depth. *v*	One-third Full Depth. Q
	Size of Sewer 4′ 8″ × 7′ 0″					
1250	4·04	101·	4·27	70·34	3·21	19·87
1500	3·68	92·17	3·9	64·21	2·93	18·14
1750	3·41	85·34	3·61	59·45	2·71	16·79
2000	3·19	79·82	3·38	55·61	2·54	15·7
2640	2·78	69·48	2·94	48·4	2·21	13·67
3000	2·60	65·18	2·76	45·4	2·07	12·83
3500	2·41	60·34	2·55	42·04	1·92	11·87
4000	2·26	56·44	2·39	39·31	1·79	11·11
	Size of Sewer 4′ 10″ × 7′ 3″					
1250	4·13	110·8	4·37	77·16	3·29	21·86
1500	3·77	101·1	3·99	70·43	3·01	19·96
1750	3·49	93·63	3·69	65·21	2·78	18·48
2000	3·26	87·59	3·45	61·	2·60	17·28
2640	2·84	76·24	3·01	53·09	2·27	15·04
3000	2·66	71·51	2·82	49·8	2·13	14·11
3500	2·47	66·21	2·61	46·11	1·97	13·06
4000	2·31	61·93	2·44	43·13	1·84	12·22
	Size of Sewer 5′ 0″ × 7′ 6″					
1500	3·86	110·8	4·08	77·07	3·07	21·82
1750	3·57	102·6	3·78	71·35	2·84	20·2
2000	3·34	95·95	3·53	66·75	2·66	18·9
2640	2·91	83·51	3·07	58·1	2·23	16·45
3000	2·73	78·34	2·88	54·5	2·17	15·43
3500	2·52	72·53	2·67	50·45	2·01	14·28
4000	2·36	67·84	2·5	47·2	1·88	13·36
5000	2·11	60·68	2·23	42·21	1·68	11·95
	Size of Sewer 5′ 4″ × 8′ 0″					
1500	4·02	131·4	4·26	91·61	3·21	25·95
1750	3·72	121·7	3·94	84·81	2·97	24·02
2000	3·48	113·8	3·69	79·33	2·78	22·47
2640	3·03	99·1	3·21	69·05	2·42	19·56
3000	2·84	92·95	3·01	64·77	2·27	18·35
3500	2·63	86·05	2·79	60·	2·1	17·
4000	2·46	80·49	2·61	56·1	1·97	15·89
5000	2·2	72·	2·33	50·18	1·76	14·21

TABLE 59.—SQUARE ROOTS.

Number. Decimal Part.	Integral Part. 0	1	2	3	4	5	6	7	8	9
·00	0·000	1·000	1·414	1·732	2·000	2·236	2·449	2·646	2·828	3·000
·05	0·224	1·025	1·432	1·746	2·012	2·247	2·460	2·655	2·837	3·008
·10	0·316	1·049	1·449	1·761	2·025	2·258	2·470	2·665	2·846	3·017
·15	0·387	1·072	1·466	1·775	2·037	2·269	2·480	2·674	2·855	3·025
·20	0·447	1·095	1·483	1·789	2·049	2·280	2·490	2·683	2·864	3·033
·25	0·500	1·118	1·500	1·803	2·062	2·291	2·500	2·693	2·872	3·041
·30	0·548	1·140	1·517	1·817	2·074	2·302	2·510	2·702	2·881	3·050
·35	0·592	1·162	1·533	1·830	2·086	2·313	2·520	2·711	2·890	3·058
·40	0·632	1·183	1·549	1·844	2·098	2·324	2·530	2·720	2·898	3·066
·45	0·671	1·204	1·565	1·857	2·110	2·335	2·540	2·729	2·907	3·074
·50	0·707	1·225	1·581	1·871	2·121	2·345	2·550	2·739	2·915	3·082
·55	0·742	1·245	1·597	1·884	2·133	2·356	2·559	2·748	2·924	3·090
·60	0·775	1·265	1·612	1·897	2·145	2·366	2·569	2·757	2·933	3·098
·65	0·806	1·285	1·628	1·910	2·156	2·377	2·579	2·766	2·941	3·106
·70	0·837	1·304	1·643	1·924	2·168	2·387	2·588	2·775	2·950	3·114
·75	0·866	1·323	1·658	1·936	2·179	2·398	2·598	2·784	2·958	3·122
·80	0·894	1·342	1·673	1·948	2·191	2·408	2·608	2·793	2·966	3·130
·85	0·922	1·360	1·688	1·962	2·202	2·419	2·617	2·802	2·975	3·138
·90	0·949	1·378	1·703	1·975	2·214	2·429	2·627	2·811	2·983	3·146
·95	0·975	1·396	1·718	1·987	2·225	2·439	2·636	2·820	2·992	3·154

	Integral Part. 10	11	12	13	14	15	16	17	18	19
·00	3·162	3·317	3·464	3·606	3·742	3·873	4·000	4·123	4·243	4·359
·25	3·202	3·354	3·500	3·640	3·775	3·905	4·031	4·153	4·272	4·387
·50	3·240	3·391	3·536	3·674	3·808	3·937	4·062	4·183	4·301	4·416
·75	3·279	3·428	3·571	3·708	3·841	3·969	4·093	4·213	4·330	4·444

	Integral Part. 20	21	22	23	24	25	26	27	28	29
·00	4·472	4·583	4·690	4·796	4·899	5·000	5·099	5·196	5·292	5·385
·25	4·500	4·610	4·717	4·822	4·924	5·025	5·123	5·220	5·315	5·408
·50	4·528	4·637	4·743	4·848	4·950	5·050	5·148	5·244	5·339	5·431
·75	4·555	4·664	4·770	4·873	4·975	5·074	5·172	5·268	5·362	5·454

	Integral Part. 30	31	32	33	34	35	36	37	38	39
·00	5·477	5·568	7.559	5·745	5·831	5·916	6·000	6·083	6·164	6·245
·25	5·500	5·590	5·766	5·766	5·852	5·937	6·021	6·103	6·184	6·265
·50	5·523	5·612	5·701	5·788	5·874	5·958	6·042	6·124	6·205	6·285
·75	5·546	5·635	5·723	5·809	5·895	5·979	6·062	6·144	6·225	6·305

CHAPTER V.

APPLICATION OF FORMULÆ.

Drainage—with Glazed Stoneware Pipes.

Size and Self-Cleansing Capacity.

Example I.

A block of buildings affording accommodation for 1,000 people, and with stabling for eight horses, has a main drain 1,072 feet in length, with an available fall of only 2·5 feet.

Each person uses five cubic feet of water, and each horse three cubic feet daily, of which one half is sent into the sewer in six hours.

A small amount of rain water is admitted in addition, amounting to about $\frac{1}{4}$ inch per hour on three acres.

(a.) What diameter of pipe will be required to carry off the maximum amount of sewage, not running quite full?

(b.) Will the minimum amount of sewage have a sufficient velocity to keep the drain clear without flushing?

The quantities of sewage, &c., to be dealt with are therefore

$$\text{Maximum discharge} = \frac{1000 \times 5 + 8 \times 3}{2 \times 6 \times 60 \times 60} = \cdot 117 \text{ cu. feet per second.}$$

$$\text{Rain water} = \frac{\frac{1}{48} \times 3 \times 4800 \times 9}{60 \times 60} = \cdot 756 \text{ cu. feet per second.}$$

$$\text{Maximum amount in sewer} = \cdot 873 \text{ cu. feet per second.}$$

First, using Darcy and Bazin's formula.

(a.) We will assume the pipe to be flowing full, then

$$v = \sqrt{\frac{2g}{\zeta}} \sqrt{\text{RS}} = k \sqrt{\text{RS}}$$

and $Q = Av$

For the approximate value of (d) we have

$$d = \cdot 2541 \sqrt[5]{\frac{Q^2}{S}} = \cdot 2541 \sqrt[5]{\frac{\cdot 873^2 \times 1072}{2 \cdot 5}}$$

$$= \cdot 81011 \text{ feet.}$$

Taking the value of (ζ) for smooth pipes from Table 47 at page 105, and substituting in the following equation, we get

$$d = \sqrt[5]{\frac{Q^2\zeta}{\pi^2 S}} = \cdot 7116 \text{ feet}$$

$$\doteq 8 \cdot 5392 \text{ inches}$$

Hence a 9-inch pipe is required.

Next, to ascertain the velocity with the maximum discharge, we will assume the depth on the invert to be ·68 of the diameter, then from the hydraulic Tables for channels with segmental cross sections, selecting that for a 9-inch pipe, we get

$$R = \cdot 21997 \text{ feet}$$

$$\text{and } A = \cdot 31991 \text{ sq. feet}$$

and for open channels,

$$v = \sqrt{\frac{2g}{\mu}} \sqrt{RS} = c\sqrt{RS}$$

$$c = 122 \cdot 78 \text{ (from Table 48, page 106)}$$

$$\therefore \; v = 122 \cdot 78 \sqrt{\cdot 21997 \times \frac{2 \cdot 5}{1072}}$$

$$\left.\begin{array}{ll} \log. \cdot 21997 & = \bar{1} \cdot 3423635 \\ \log. 2 \cdot 5 & = 0 \cdot 3979400 \\ \text{colog. } 1072 & = 6 \cdot 9698052 \end{array}\right\} - 10$$

$$2)\overline{\bar{1} \cdot 7101087}$$

$$\bar{2} \cdot 3550543$$

$$\log. 122 \cdot 78 = 2 \cdot 0891551$$

$$\therefore \; \log 2 \cdot 78 = 0 \cdot 4442094$$

$$\text{and } v = 2 \cdot 78 \text{ feet per second}$$

$$Q = Av$$

$$= \cdot 31991 \times 2 \cdot 78$$

$$\left.\begin{array}{ll} \log. \cdot 31991 & = \bar{1} \cdot 5050278 \\ \log. 2 \cdot 78 & = 0 \cdot 4442094 \end{array}\right\}$$

$$\log. \cdot 88968 = \bar{1} \cdot 9492372$$

$$\therefore \; Q = \cdot 88968 \text{ cu. feet per second,}$$

which is slightly in excess of the maximum amount required, viz., ·873 cubic feet per second.

A nearer approximation to the velocity could if necessary be obtained by taking the depth on the invert as ·67 of the diameter, and proceeding as before until a satisfactory result is arrived at.

(b.) For the minimum discharge we will assume the depth on the invert to be ·225 of the diameter of the pipe.

Then from Table 31 for a 9-inch pipe, page 90, we have

$$R = \cdot 10035 \text{ feet}$$

$$\text{and } A = \cdot 074412 \text{ sq. feet.}$$

$$\text{Now } v = c\sqrt{RS}, \text{ and } S = \frac{2\cdot 5}{1072}$$

$$\text{and } c = 104\cdot 98 \text{ (from Table 48, page 106)}$$

$$\left.\begin{array}{ll} \text{log. } \cdot 10035 & = \bar{1}\cdot 0015174 \\ \text{log. } 2\cdot 5 & = 0\cdot 3979400 \\ \text{colog. } 1072 & = 6\cdot 9698052 \end{array}\right\} - 10$$

$$2)\bar{4}\cdot 3692626$$

$$\bar{2}\cdot 1846313$$

$$\text{log. } 104\cdot 98 = 2\cdot 0211066$$

$$\text{log. } 1\cdot 6059 = 0\cdot 2057379$$

$$\therefore v = 1\cdot 606 \text{ feet per second}$$

$$\text{and } Q = Av$$

$$\left.\begin{array}{l} \text{log. } A = \bar{2}\cdot 8716430 \\ \text{log. } v = 0\cdot 2057379 \end{array}\right\}$$

$$\text{log. } \cdot 1195 = \bar{1}\cdot 0773809$$

$$\therefore Q = \cdot 1195 \text{ cu. feet per second.}$$

This approximation is also sufficiently close to the actual amount, viz., ·117 cubic feet per second, so that no further calculation is necessary; otherwise a new depth on the invert would be taken, and the calculations repeated with the new depth.

The gradient of the pipe is thus found to be insufficient to give a self-cleansing velocity, so that flushing would have to be resorted to.

Secondly, solving the same questions by Ganguillet and Kutter's formula.

The method to be adopted is that of trial and error.

(a.) We have the following data to work with:—

$$S = \frac{2\cdot 5}{1072} = \cdot 002332 \text{ and } \sqrt{S} = \cdot 048 \text{ (Table 50, page 111,)}$$

and taking $n = 0\cdot 01$

Maximum discharge = ·873 cubic feet per second, and if we assume a minimum self-cleansing velocity of three feet per second, then the area of cross section of stream

$$= \frac{\cdot 873}{3} = \cdot 291 \text{ sq. feet.}$$

If now we refer to the hydraulic Tables (25 to 42, pages 84—101), for segmental cross sections, and neglecting those which are only obtainable in iron, we find without any calculation that a 9-inch glazed pipe is required to give a cross section of ·291 square feet. We will assume the stream to be flowing to a depth of ·70 of the diameter of the pipe, then from the same Table we get

$$A = \cdot 330 \text{ sq. feet and } \sqrt{R} = \cdot 471 \text{ feet.}$$

Now $$v = c\sqrt{RS}$$

where $$c = \frac{a + \frac{l}{n} + \frac{m}{S}}{1 + \left(a + \frac{m}{S}\right)\frac{n}{\sqrt{R}}}$$

Now to find (c)

we have
$$\left.\begin{array}{r} a = 41\cdot 66 \\ m = \cdot 000281 \\ l = 1\cdot 811 \end{array}\right\} \text{Constants, Table 7, page 51.}$$

and
$$\left.\begin{array}{r} \frac{l}{n} = 181\cdot 13 \\ a + \frac{m}{S} = 42\cdot 8649 \end{array}\right\} \text{from Tables 49 and 50, pages 107 and 108.}$$

$$223\cdot 9949$$

$$\left.\begin{array}{ll} \log.\left(a + \frac{m}{S}\right) = & {}^{-}1\cdot 6321018 \\ \log.\ n = & \bar{2}\cdot 0000000 \\ \text{colog.}\ \sqrt{R} = & 10\cdot 3266555 \end{array}\right\} - 10$$

$$\log.\ \cdot 90940 = \bar{1}\cdot 9587573$$

$$\therefore\ 1 + \left(a + \frac{m}{S}\right)\frac{n}{\sqrt{R}} = 1\cdot 9094$$

$$\left.\begin{array}{ll} \log.\ 223\cdot 9949 = & 2\cdot 3502381 \\ \log.\ \ 1\cdot 9094 = & 0\cdot 2808969 \end{array}\right\}$$

$$\log.\ \ 117\cdot 28 = 2\cdot 0692412$$

$$\therefore\ c = 117\cdot 28$$

The value of (c) may be more readily obtained from the Diagram, Plate LXI.,* by joining the point on the scale where the $\sqrt{R} = \cdot 471$ with the point where the slope curve ·0023 cuts the (n) line 0·01 ; the intersection of the line thus drawn with the scale of (c) gives the value of (c) on the scale. It is convenient to use a couple of pins and a fine silk thread for the purpose.

Then $$v = c\sqrt{R} \times \sqrt{S} = 117\cdot 28 \times \cdot 471 \times \cdot 048$$
$$= 2\cdot 6696 \text{ feet per second.}$$

And $$Q = Av = \cdot 330318 \times 2\cdot 6696$$
$$= \cdot 88183 \text{ cu. feet per second,}$$

which is a very close approximation to the maximum discharge, viz.,

* Placed at end of book for convenience when in use.

8·73 cubic feet per second, which has to be provided for, so no further calculation is required in this instance.

The above calculation is much simplified by the use of the Author's Form of Ganguillet and Kutter's formula, as advocated at page 54, where we have

$$v = \frac{\frac{l}{n} + \left(a + \frac{m}{S}\right)}{\sqrt{R} + \left(a + \frac{m}{S}\right)n} R \sqrt{S}$$

From Tables 49 and 50, we have as above

$$\frac{l}{n} + \left(a + \frac{m}{S}\right) = 223{\cdot}9949$$

$$\left(a + \frac{m}{S}\right)n = 42{\cdot}8649 \times {\cdot}01 = {\cdot}4286$$

From Table 31 $\sqrt{R} = {\cdot}4713$

$${\cdot}8999$$

$$\left.\begin{array}{rl} \log.\ 223{\cdot}9949 = & 2{\cdot}3502381 \\ \log.\ R = \log.\ {\cdot}2221 = & \bar{1}{\cdot}3465486 \\ \log.\ \sqrt{S} = \log.\ {\cdot}04829 = & \bar{2}{\cdot}6838572 \\ \text{colog.}\ {\cdot}8999 = & 10{\cdot}0458057 \end{array}\right\} - 10$$

$$\log.\ v = \log.\ 2{\cdot}6696 = 0{\cdot}4264496$$

$$\therefore v = 2{\cdot}6696 \text{ feet per second}$$

as already obtained. A comparison of the two methods of working shows that the latter is much the simpler of the two, and the advantage of using the Labour Saving Tables prepared for this work is very apparent.

(b.) Similarly for the minimum discharge, taking the depth on the invert as ·23 of the diameter, we get

$$A = {\cdot}0767 \text{ sq. feet}$$
$$\sqrt{R} = {\cdot}3198 \text{ feet}$$
and $c = 95{\cdot}5$ (from Diagram)

then $v = c\sqrt{RS}$

$$= 95{\cdot}5 \times {\cdot}3198 \times {\cdot}048$$
$$= 1{\cdot}466 \text{ feet per second}$$

and $Q = Av = {\cdot}0767 \times 1{\cdot}466$

$$= {\cdot}1124 \text{ cu. feet per second.}$$

This approximation is also sufficiently near for our purpose.

The velocity obtained is too low for the drain to be self-cleansing, so flushing must be resorted to.

Slope.

Example II.

To ascertain in the previous Example the slope required to give a self-cleansing velocity to the maximum amount of sewage to be conveyed.

We have for a 3-feet velocity :—

$$\text{Area of cross section of stream} = \frac{\cdot 873}{3} = \cdot 291 \text{ sq. feet.}$$

With a 9-inch pipe this cross section involves a depth of ·63 of the diameter.

$$\text{then } R = \cdot 2131 \text{ and } \sqrt{R} = \cdot 461.$$

First, by Darcy and Bazin's formula.

$$v = c\sqrt{RS} \qquad c = 123 \text{ (from Table)}$$

$$\text{or } 3 = 123 \times \cdot 461 \sqrt{S}$$

$$\therefore S = \cdot 002799.$$

Second, by Ganguillet and Kutter's formula.

$$v = c\sqrt{RS} \qquad c = 115\cdot 5 \text{ (from Diagram)}$$

$$\therefore 3 = 115\cdot 5 \times \cdot 461 \sqrt{S}$$

$$\therefore S = \cdot 003174.$$

Angular Section.

Example III.

It is required to ascertain the dimensions for an open channèl of angular section to convey 10,000 gallons per minute with a surface slope of 5 in 10,000.

The channel is to be constructed of ashlar masonry in large blocks, and neatly dressed, the bottom is to be horizontal, and the side walls are to have a slope of 4 over 1.

We thus have

$$S = \cdot 0005 \text{ and } \sqrt{S} = \cdot 022$$

$$Q = \frac{10,000}{6\cdot 23 \times 60} = 26 \text{ cu. feet per second.}$$

First, using Darcy and Bazin's formula.

We will assume a velocity of 3 feet per second.

$$\text{thus } A = \frac{26}{3} = 8\cdot 66 \text{ sq. feet,}$$

and taking depth of stream at 2 feet we get the average width $= 4\cdot 3$ feet.

The wetd. per. $= (4\cdot 3 - \cdot 5) + 2\cdot 06 \times 2 = 7\cdot 92$ feet

$$\therefore R = \frac{8\cdot 66}{7\cdot 92} = 1\cdot 09 \text{ and } \sqrt{R} = 1\cdot 04$$

$$v = c\sqrt{RS} \text{ where } c = \sqrt{\frac{2g}{\mu}}$$

$$\text{and } \mu = \alpha\left(1 + \frac{\beta}{R}\right)$$

$$\alpha = \cdot 0037285 \qquad \beta = \cdot 2296629$$

$$\frac{\beta}{R} = \frac{\cdot 2296629}{1\cdot 09} = \cdot 21069$$

$$\therefore \mu = \cdot 0037285 \times 1\cdot 21069$$

$$\log. 2g = \quad 1{\cdot}8087615$$
$$\log. a \quad = \bar{3}{\cdot}5715340$$
$$\log. \left(1 + \frac{\beta}{R}\right) = 0{\cdot}0820293$$
$$\bar{3}{\cdot}6535633$$
$$2)\bar{4}{\cdot}1551982$$
$$\log. c = \log. 119{\cdot}56 = 2{\cdot}0775991$$
$$\therefore c = 119{\cdot}56$$

From this we must make a deduction of 6·2 (say) for an angular section (page 47), and we get $c = 113{\cdot}36$.

$$\therefore v = c\sqrt{RS} = 113{\cdot}36 \times 1{\cdot}04 \times {\cdot}022$$
$$= 2{\cdot}59 \text{ feet per second.}$$

This is too slow a velocity with the section chosen.

We will next try an average width of 5 feet.

Then $\quad$ area $= 5 \times 2 = 10$ sq. feet,

and wetd. per. $= 2{\cdot}06 \times 2 + 4{\cdot}5 = 8{\cdot}62$ feet,

$$\therefore R = \frac{10}{8{\cdot}26} = 1{\cdot}16 \text{ and } \sqrt{R} = 1{\cdot}07$$

Now $\quad v = c\sqrt{RS}$ where $c = \sqrt{\frac{2g}{\mu}}$

$$\text{and } \mu = a\left(1 + \frac{\beta}{R}\right)$$
$$\frac{\beta}{R} = \frac{{\cdot}2296629}{1{\cdot}16} = {\cdot}19798$$
$$\therefore \mu = {\cdot}0037285 \times 1{\cdot}19798$$
$$\log. 2g = \quad 1{\cdot}8087615$$
$$\log. a = \bar{3}{\cdot}5715340$$
$$\log. \left(1 + \frac{\beta}{R}\right) = 0{\cdot}0784497$$
$$\bar{3}{\cdot}6499837$$
$$2)\bar{4}{\cdot}1587778$$
$$\therefore \log. c = \log. 120{\cdot}05 = 2{\cdot}0793889$$
$$\therefore c = 120{\cdot}05.$$

Deducting 6·2 for angular section we get $c = 113{\cdot}85$

$$\therefore v = 113{\cdot}85 \times 1{\cdot}07 \times {\cdot}022$$
$$= 2{\cdot}68 \text{ feet per second,}$$
$$\text{and } Q = Av = 10 \times 2{\cdot}68$$
$$= 26{\cdot}8 \text{ cu. feet per second}$$
$$= 10{,}017 \text{ gallons per minute,}$$

which is quite near enough.

Second, employing Ganguillet and Kutter's formula.

The value of (n) in this case comes under Category III. (Table 4, page 46), but as the section is angular and not semicircular, a larger value of (n) than ·013 therein given must be taken (*vide* Tables 51—54).

Take $n = \cdot 014$ and proceeding as before, we get an assumed channel 2 feet deep with an average width of 4·3 feet, with $\sqrt{R} = 1\cdot 04$ and $S = \cdot 0005$, $\sqrt{S} = \cdot 022$, we then get $c = 107\cdot 5$ (from Diagram)

$$\text{and } v = c\sqrt{RS} = 107\cdot 5 \times 1\cdot 04 \times \cdot 022$$
$$= 2\cdot 45 \text{ feet per second.}$$

This velocity is too small, so a larger section must be tried.

Try a similar section with an average width of 4 feet 9 inches.

Then $$\text{area} = 4\cdot 75 \times 2 = 9\cdot 5 \text{ sq. feet}$$
$$\text{and wetd. per.} = 4\cdot 25 + 2\cdot 06 \times 2 = 8\cdot 37 \text{ feet,}$$
$$\therefore R = 1\cdot 13 \text{ and } \sqrt{R} = 1\cdot 06$$
$$\therefore c = 108 \text{ (from Diagram)}$$
$$v = c\sqrt{RS} = 108 \times 1\cdot 06 \times \cdot 022$$
$$= 2\cdot 518 \text{ feet per second}$$
$$\therefore Q = 9\cdot 5 \times 2\cdot 518 = 23\cdot 92 \text{ cu. feet per second.}$$

This quantity is too small; we will now try a similar section of 5 feet width (average).

Then $$\text{area} = 5 \times 2 = 10 \text{ sq. feet}$$
$$\text{and wetd. per.} = 2\cdot 06 \times 2 + 4\cdot 5 = 8\cdot 62 \text{ feet}$$
$$\therefore R = \frac{10}{8\cdot 62} = 1\cdot 16 \text{ and } \sqrt{R} = 1\cdot 07$$
$$\therefore c = 108\cdot 5 \text{ (from Diagram)}$$
$$\therefore v = c\sqrt{RS} = 108\cdot 5 \times 1\cdot 07 \times \cdot 022$$
$$= 2\cdot 554 \text{ feet per second}$$
$$\therefore Q = Av = 10 \times 2\cdot 554$$
$$= 25\cdot 54 \text{ cu. feet per second.}$$

This is still too small; we will therefore increase the average width to 5 feet 3 inches.

Then $$\text{area} = 5\cdot 25 \times 2 = 10\cdot 5 \text{ sq. feet}$$
$$\text{wetd. per.} = 2\cdot 06 \times 2 + 4\cdot 75 = 8\cdot 87 \text{ feet}$$
$$\therefore R = \frac{10\cdot 5}{8\cdot 87} = 1\cdot 1837 \text{ and } \sqrt{R} = 1\cdot 08$$
$$\text{and } c = 109 \text{ (from Diagram)}$$
$$\therefore v = c\sqrt{RS} = 109 \times 1\cdot 08 \times \cdot 022$$
$$= 2\cdot 56 \text{ feet per second,}$$
$$\text{and } Q = 10\cdot 5 \times 2\cdot 56$$
$$= 26\cdot 95 \text{ cu. feet per second}$$
$$= 10{,}073 \text{ gallons per minute,}$$

which is just on the safe side, so this last section might be adopted.

Water Supply with Cast-Iron and Wrought-Iron Pipes.

Example IV.

A tank is to be supplied from a reservoir under the following conditions:—

The difference of level between the ball-cock in the tank, and the surface of the water in the reservoir (Fig. 50) is 30 feet; and the length of pipe is 2,350 yards; the tank is to hold 5,000 gallons, and the total amount is to be supplied to it at the rate of one-fourth in one hour.

What must be the size of the supply pipe? the following *minor losses* of head being allowed for :—

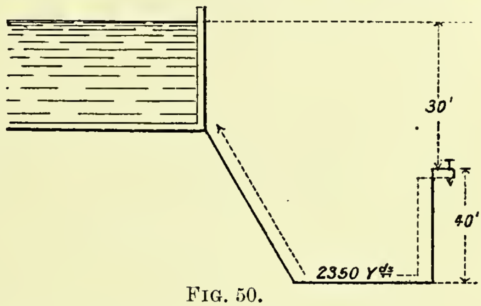


FIG. 50.

(1.) Orifice of entry.
(2.) Velocity.
(3.) Three elbows of 20° each } in length of pipe.
(4.) One bend of 90° }

Now

$$Q = \frac{5000}{6 \cdot 2321 \times 60 \times 60 \times 4} \text{ cu. feet per second}$$
$$= \cdot 0557 \quad " \quad " \quad "$$

$$\text{and } S = \frac{30}{2350 \times 3} = \frac{1}{235} = \cdot 00425.$$

First, using Darcy and Bazin's formula to find (d) approximately.

$$d = 0 \cdot 2541 \sqrt[5]{\frac{Q^2}{S}} = 0 \cdot 24075 \text{ (by substitution)},$$

and $\zeta = 0 \cdot 013461$ (deduced from Table 47, page 105).

Again $$d = \sqrt[5]{\frac{Q^2 \zeta}{\pi^2 S}} = 3 \cdot 01116 \text{ inches} = 3 \text{ inches (say)}$$

$$\text{and } v = k\sqrt{RS} = \frac{k}{2}\sqrt{dS} = \frac{70}{2}\sqrt{\frac{1}{4} \times \frac{1}{235}}$$
$$= 1 \cdot 145 \text{ feet per second.}$$

Therefore

$$Q = Av = \cdot 049087 \times 1 \cdot 145 \text{ cu. feet per second}$$
$$= 5028 \cdot 8 \text{ gallons in 4 hours.}$$

MINOR LOSSES OF HEAD.

Loss due to Velocity of 1·145 feet per second.

$$H_v = v^2 \times 0 \cdot 0155$$
$$= (1 \cdot 145)^2 \times 0 \cdot 0155$$
$$= \cdot 0203208 \text{ feet.}$$

Loss due to Bell-mouthed Orifice.—This may be taken as corresponding to No. IV. description in Table 12 of coefficients for orifices; then (n) = ·000918,

and $$H_o = \cdot 000918 \times v^2$$
$$= \cdot 000918 \times (1 \cdot 145)^2$$
$$= \cdot 001204 \text{ feet.}$$

Three Elbows.

$$H_a = V^2 \times \frac{m}{2g}$$

$\therefore$ Here $H_a = (1{\cdot}145)^2 \times {\cdot}0004 \times 3$

$= {\cdot}0005244$ feet.

Circular Bend.

If ρ = radius of axis of bend = 15 inches
d = diameter of pipe = 3 inches

Then

$$\frac{d}{2\rho} = \frac{3}{30} = {\cdot}1$$

and $m_b = {\cdot}0000113$

$\therefore H_b = m_b \times (1{\cdot}145)^2$
$= {\cdot}0000148.$

$\therefore$ Total loss of head is as follows:—

Velocity	=	·020321
Orifice	=	·001204
Elbows	=	·000524
Circular bend	=	·000015
Total loss	=	·022064 feet.

This is so small an amount that it is not worth while recalculating.

Secondly, using Ganguillet and Kutter's formula, and proceeding by trial and error; we will try a 3-inch cast-iron pipe in the first place.

We have

$S = {\cdot}00425$ $\therefore \sqrt{\ } = {\cdot}065$
$\sqrt{R} = {\cdot}250$ feet $A = {\cdot}049087$ for a 3-inch pipe.
$n = {\cdot}0125$
$c = 60{\cdot}2$ (from Diagram);
$\therefore v = c\sqrt{RS} = 60{\cdot}2 \times {\cdot}25 \times {\cdot}065$
$= {\cdot}97825$ feet per second,
and $Q = Av = {\cdot}049087 \times {\cdot}97825$
$= {\cdot}48$ cu. feet per second;

but as this is less than the amount required, the next size of pipe, viz., 4 inches, would have to be employed; then to find its capacity, we have

$\sqrt{R} = {\cdot}28867$ feet $A = {\cdot}087266$ sq. feet.
and $c = 66$ (from Diagram);
$\therefore v = c\sqrt{RS} = 66 \times {\cdot}28867 \times {\cdot}065$
$= 1{\cdot}238$ cu. feet per second,
and $Q = Av = {\cdot}049087 \times 1{\cdot}238$ feet per second
$= 5453{\cdot}6$ gallons in 4 hours.

The method of ascertaining the minor losses of head need not be repeated, but as the diameter of the pipe found to be necessary is greater than by Darcy and Bazin's formula, the loss of head would be less than that calculated for a 3-inch pipe.

Services.

Example V.

(a.) It is required to ascertain the sizes for the supply pipes to a house arranged as in Fig. 51, in order that the upper tap may discharge 4 gallons per minute, concurrently with a discharge of 3 gallons per minute from the lower tap; the available head, which is not much more than sufficient for the purpose, is to be economized as much as possible.

(b.) Also to ascertain what the discharge from the two taps will be separately, with a definite pressure in the main.

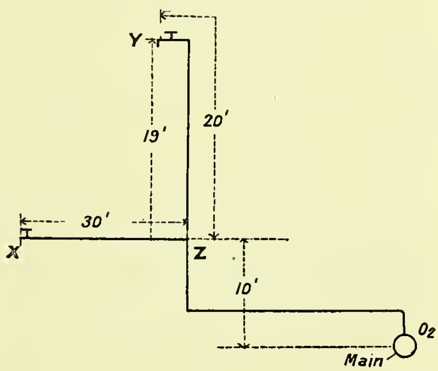


Fig. 51.

For economy of power the resistance caused by the horizontal supply pipe to the lower tap should afford sufficient head to give the necessary discharge at the upper tap.

The required result is best attained by the system of trial and error.

First, employing Darcy and Bazin's formula.

Now, assuming a $\frac{1}{2}$-inch pipe for the portion XZ, we have

$$v = \frac{k}{2}\sqrt{dS} = \frac{k}{2}\sqrt{\frac{dh}{l}}$$

and $k = 46$ (from Table 47, page 105)

$$\therefore Q = Av = \frac{\pi d^2}{4} \times \frac{k}{2}\sqrt{\frac{dh}{l}} = \frac{k}{8}\sqrt{\frac{\pi^2 d^5 h}{l}}$$

$$\therefore h = \frac{l}{\pi^2 d^5} \times \frac{8^2 Q^2}{k^2} = 83{\cdot}56 \text{ feet.}$$

This is considerably more than the difference of level of the two taps, viz., 19 feet; we will now try a 1-inch pipe, and proceeding as before, we get $h = 1{\cdot}7$ feet; this on the other hand is too little. Next trying a $\frac{5}{8}$-inch pipe, we get $h = 24{\cdot}13$ feet, which being slightly in excess of the difference of level (19 feet) is probably near enough.

We must now ascertain what addition is required to compensate for *minor losses.*

To find the velocity of discharge through a $\frac{5}{8}$-inch old pipe (XZ) with a head of 24·13 feet at Z :—

$$v = \frac{k}{2}\sqrt{dS} = \frac{49}{2}\sqrt{\frac{5}{96} \times \frac{24 \cdot 13}{30}}$$

$$= 5 \cdot 0146 \text{ feet per second.}$$

Head due to this velocity :—

$H_v = \frac{v^2}{2g} = \cdot 3904$ feet	=	·3904 feet.
Loss due to gurglitation $= 2H_v$	=	·7808
Loss due to gurglitation and velocity	=	1·1712 feet.

Now supposing the box of the tap to reduce the waterway to $\frac{1}{2}$-inch diameter, the velocity of discharge must be increased, with a consequent addition to the resistance.

And, if in these two cases we have

$$Q = \frac{\pi d^2}{4} \times v$$

$$\text{and} \quad Q_1 = \frac{\pi d_1^2}{4} \times v$$

then, as the quantity is the same in both cases,

$$Q = Q$$

$$\text{and} \quad d^2 v = d_1^2 v_1$$

$$\therefore v_1 = \left(\frac{d}{d_1}\right)^2 v = \left(\frac{5}{96} \times 24\right)^2 \times 5 \cdot 0146$$

$$= 7 \cdot 8353 \text{ feet per second (increased velocity).}$$

Loss of head to produce this velocity in tap $= \frac{v_1^2}{2g}$	=	·9533 feet.
Original loss H_v	=	·3904
Total additional loss due to issue	=	·5629
Losses due to velocity and gurglitation	=	1·1712
Total *minor losses*	=	1·7341
and h	=	24·13
∴ Total head required at Z	=	25·86
Difference of level between Z and Y	=	19
∴ Effective head at Y	=	6·86 feet.

Next to ascertain the size required for YZ, assuming a $\frac{3}{4}$-inch pipe,

$$\text{then } k = 53 \text{ (Table 47)}$$

and as before, by substituting corresponding values in the equation

$$h = \frac{l}{\pi^2 d} \times \frac{8^2 Q^2}{k^2} = 2 \cdot 9684 \text{ feet.}$$

To ascertain minor losses, it is necessary to find the velocity of flow.

$$\text{Now, } v = \frac{k}{2}\sqrt{\frac{dh}{l}}$$

$$= \frac{53}{8}\sqrt{\frac{3}{4 \times 12} \times \frac{6{\cdot}86}{20}} = 3{\cdot}88 \text{ feet per second,}$$

and loss due to this velocity alone

$$= H_v = \frac{v^2}{2g} = {\cdot}2332 \text{ feet.}$$

To find loss due to two bends, taking $\frac{d}{2\rho} = {\cdot}3$ (Table 14, page 63)

$$2H_b = 2 \times {\cdot}000013 \times 90° \times 3{\cdot}88^2$$
$$= {\cdot}0352 \text{ feet.}$$

Next, to find loss due to a reduction of bore from three-quarters inch to five-eighths inch (say) for tap.

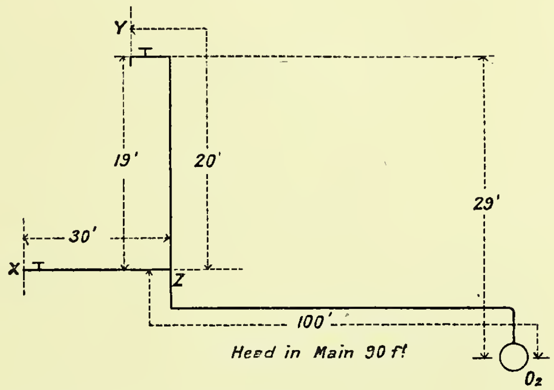


FIG. 52.

The velocity of discharge will now be increased to v_1

then $v_1 = \left(\frac{d}{d_1}\right)^2 v$ as above

$$= \left(\frac{3}{4 \times 12} \times \frac{8 \times 12}{5}\right)^2 \times 3{\cdot}88 = 5{\cdot}5872 \text{ feet per second.}$$

The loss of head to produce this velocity

$$= H_{v_1} = \frac{v_1^2}{2g} = \frac{(5{\cdot}58)^2}{2g} = {\cdot}4848 \text{ feet}$$

which includes that due to ordinary velocity.

Total minor losses are therefore

$$2H_b = {\cdot}0352 \text{ feet.}$$
$$H_{v_1} = {\cdot}4848$$
$$\overline{{\cdot}5250}$$

and from above $h = 2{\cdot}9684$

Total effective head required at Y = 3·4934 feet.

To meet which the actual available head would be 6·86 feet, so that a $\frac{3}{4}$-inch pipe would be amply large.

A close approximation to the actual discharge at Y could now be obtained by recalculating with an assumed head of 5·5 feet allowing the balance between this and 6·86 feet or 1·36 feet to be absorbed by minor losses. When new, the discharging power of both taps would be greater than that thus obtained for encrusted pipes.

(b.) In the next place we will consider the question of supply through these taps separately, on the assumption that the head in the main (Fig. 52) has been found by a pressure gauge to be 90 feet.

First, we will assume that the tap Y is open, and that at X is closed; then the available head of pressure is $90 - 19 - 10 = 61$, or, say, 59·5 feet, allowing for minor losses.

Now, $Q = \frac{\pi d^2}{4} \times \frac{k}{2}\sqrt{dS}$

$$= \frac{\pi}{4}\left(\frac{1}{16}\right)^2 \times \frac{53}{2}\sqrt{\frac{1}{16} \times \frac{59 \cdot 5}{120}} \text{ (for a } \tfrac{3}{4}\text{-inch pipe)}$$

$$= \frac{\pi \times 53}{8 \times 16 \times 16 \times 4}\sqrt{\frac{59 \cdot 5}{30}} \text{ feet per second}$$

$$= \frac{\pi \times 53 \times 60 \times 6 \cdot 23}{16 \times 16 \times 32}\sqrt{\frac{59 \cdot 5}{30}} \text{ (gallons per minute)}$$

$= 10·7$ gallons per minute.

We will now assume that the tap X is open and that at Y is closed.

We have now to deal with two sizes of pipe :—

Let (h) = the head of pressure available at Z, thus allowing one foot for the minor losses between O_2 and Z, we have

Head of pressure available for $O_2Z = 90 - 11 - h = 79 - h$, and for $XZ = h$. As O_2Z is a $\frac{3}{4}$-inch pipe, we get

$$Q = \frac{\pi}{4}\left(\frac{1}{16}\right)^2 \times \frac{53}{2}\sqrt{\frac{1}{16} \times \frac{79 - h}{100}} \quad . \quad . \quad (1)$$

and for XZ, which is a $\frac{5}{8}$-inch pipe, we have

$$Q = \frac{\pi}{4}\left(\frac{5}{96}\right)^2 \times \frac{49}{2}\sqrt{\frac{5}{96} \times \frac{h}{30}} \quad . \quad . \quad . \quad (2)$$

Equating (1) and (2)

$$\left(\frac{1}{16}\right)^2 \times \frac{53}{40}\sqrt{79 - h} = \left(\frac{5}{96}\right)^2 \times \frac{49}{24}\sqrt{h}$$

$$\therefore \sqrt{79 - h} = \left(\frac{5}{96} \times 16\right)^2 \times \frac{49 \times 40}{24 \times 53}\sqrt{h}$$

$$= \frac{5^2 \times 49 \times 5}{6^2 \times 3 \times 53}\sqrt{h}$$

$$= 1 \cdot 07\sqrt{h}$$

$$\therefore 79 - h = 1 \cdot 1449h$$

$$\therefore 2 \cdot 1449h = 79$$

$$\therefore \quad h = 36 \cdot 8 \text{ feet.}$$

To ascertain discharge we will allow one foot for minor losses :—

Then $$Q = \frac{\pi}{4}\left(\frac{5}{96}\right)^2 \times \frac{49}{2}\sqrt{\frac{5}{96} \times \frac{35 \cdot 8}{30}} \text{ feet per second}$$

$$= \frac{\pi \times 5^2 \times 49}{8 \times 96^2 \times 24}\sqrt{35 \cdot 8} \times 60 \times 6 \cdot 23 \text{ gallons per minute}$$

$= 4·86$ gallons per minute.

Second, using Ganguillet and Kutter's formula.

(a.) We will assume a $\frac{1}{2}$-inch wrought-iron pipe, not galvanized and slightly encrusted for XZ (Table 54, page 126).

Then we have

$$n = \cdot 0125$$

$$S = \frac{19}{30} \text{ at least, which is over 1 in 10.}$$

$$\sqrt{R} = \cdot 101 \text{ feet as } R = \frac{d}{4} = \cdot 0104 \text{ feet}$$

$$\therefore c = 31 \text{ (from the Diagram)}$$

$$\text{and } A = \frac{\cdot 78539 \times \cdot 5 \times \cdot 5}{144} = \cdot 00136 \text{ sq. feet}$$

$$Q = \frac{3}{6\cdot 23 \times 60} = \cdot 0080256 \text{ cu. feet per second.}$$
$$= Av$$

Now
$$v = c\sqrt{R}\sqrt{\frac{h}{l}} = 31 \times \cdot 101\sqrt{\frac{h}{30}} = 56\sqrt{h}$$
$$= \frac{Q}{A} = \frac{\cdot 0080256}{\cdot 00136} = 5\cdot 9$$

$$\therefore \sqrt{h} = \frac{5\cdot 9}{\cdot 56} = 10\cdot 5 \text{ and } h = 110 \text{ feet.}$$

This is too great a head, and another diameter of pipe must be tried. N.B.—If a new galvanized iron pipe had been considered with $n = \cdot 0082$ and $c = 60$, the value of (h) would have been found to be 28·09 feet, the difference in the value of (h) being due to the respective natures of the interior surface of the pipes. We will now try a 1-inch pipe.

Here
$$n = \cdot 0215, \text{ as before}$$

$$R = \frac{d}{4} = \cdot 0208 \text{ feet} \therefore \sqrt{R} = \cdot 144$$

$$S \text{ is greater than } 0\cdot 1 \therefore c = 41 \text{ (from Diagram)}$$

$$A = \frac{\cdot 78539}{12 \times 12} = \cdot 00545 \text{ feet}$$

$$\text{and } v = c\sqrt{R}\sqrt{\frac{h}{l}} = 41 \times \cdot 144\sqrt{\frac{h}{30}} = 1\cdot 07\sqrt{h}$$
$$= \frac{Q}{A} = \frac{\cdot 0080256}{\cdot 00545} = 1\cdot 47$$

$$\therefore \sqrt{h} = 1\cdot 37 \text{ and } h = 1\cdot 87 \text{ feet.}$$

This head would be insufficient to comply with the conditions. We will next try a $\frac{3}{4}$-inch pipe, then

$$A = \frac{\cdot 78539 \times \cdot 75^2}{144} = \cdot 0030679 \text{ sq. feet ;}$$

$$\text{and } \sqrt{R} = \cdot 125 \text{ feet as } R = \frac{\cdot 75}{4 \times 12} = \cdot 015625 \text{ feet.}$$

$$c = 37 \text{ (from Diagram).}$$

Now $$v = c\sqrt{\text{R}}\sqrt{\frac{h}{l}} = 37 \times {\cdot}125\sqrt{\frac{h}{30}} = {\cdot}83\sqrt{h}$$

$$= \frac{\text{Q}}{\text{A}} = \frac{{\cdot}0080256}{{\cdot}0030679} = 2{\cdot}61$$

$$\therefore \quad \sqrt{h} = 3{\cdot}1 \text{ and } h = 9{\cdot}61 \text{ feet.}$$

This is still too little; next try a $\frac{5}{8}$-inch pipe, then,

$$\text{A} = \frac{{\cdot}78539 \times 5^2}{12^2 \times 8^2} = {\cdot}00213 \text{ sq. feet,}$$

$$\text{and} \quad \sqrt{\text{R}} = {\cdot}114 \text{ as R} = \frac{5}{4 \times 8 \times 12} = {\cdot}01302 \text{ feet,}$$

$$\therefore \; c = 34{\cdot}5 \text{ (from Diagram);}$$

$$\text{and} \quad v = c\sqrt{\text{R}}\sqrt{\frac{h}{l}} = 34{\cdot}5 \times {\cdot}114\sqrt{\frac{h}{30}} = {\cdot}719\sqrt{h}$$

$$= \frac{\text{Q}}{\text{A}} = \frac{{\cdot}0080256}{{\cdot}00213} = 3{\cdot}76$$

$$\therefore \quad \sqrt{h} = 5{\cdot}2 \text{ and } h = 27{\cdot}04 \text{ feet,}$$

which being slightly in excess of the difference in level of the two taps, viz., 19 feet, is probably near enough.

We must now ascertain what addition will be required to cover minor losses, and for this purpose the velocity of discharge through the $\frac{5}{8}$-inch pipe YZ with a head of 27·04 feet must be obtained.

$$v = c\sqrt{\text{RS}} = 34{\cdot}5 \times {\cdot}114\sqrt{\frac{27{\cdot}04}{30}} = 3{\cdot}697 \text{ feet per second.}$$

$$\text{Q} = \text{A}v = {\cdot}00787 \text{ cu. feet} = 2{\cdot}94 \text{ gallons per minute.}$$

Head due to velocity	$= \frac{v^2}{2g}$	$= \text{H}_v =$	·212 feet.
,, ,, gurglitation		$= 2\text{H}_v =$	·424
Loss of head from these two causes		$=$	·636 feet.

Supposing the bore of the tap to reduce the waterway to $\frac{1}{2}$-inch diameter ($\frac{1}{24}$th of a foot) the velocity of discharge will have to be increased, and the resistance will also be greater.

Now $$\text{Q} = \text{A}v = \frac{\pi d^2}{4} v$$

$$\text{and} \quad \text{Q}_1 = \frac{\pi d_1^2}{4} v_1$$

but as the quantity is the same in both cases—

$$d^2 v = d_1^2 v_1^2$$

$$\therefore \quad v_1 = \left(\frac{d}{d_1}\right)^2 v = \left(\frac{5}{5 \times 12} \div \frac{1}{24}\right)^2 \times 3{\cdot}697$$

$$= 5{\cdot}76 \text{ feet per second.}$$

Loss of head to produce this velocity in the tap $= \frac{v_1^2}{2g} = {\cdot}515$ feet.

We thus have—

Loss due to increased velocity of issue	=	·515 feet.
Deduct original loss H_v	=	·212
Total additional loss due to issue	=	·303
Losses due to velocity and gurglitation	=	·636
Total minor losses	=	·939
Original head	=	27·04
Total head required at Z	=	27·979
	or	28 feet (say)
Difference in level between Z and Y	=	19
∴ Head at Y	=	9 feet.

Next to ascertain the size required for the pipe YZ, to discharge four gallons per minute with a head not exceeding 9 feet.

Try a three-quarter inch pipe, then (c) remains as before = 37, and $\sqrt{R} = \cdot 125$

$$\therefore \quad v = c\sqrt{R}\sqrt{\frac{h}{l}} = 37 \times \cdot 125\sqrt{\frac{h}{20}} = 1\cdot 029\sqrt{h}$$

$$= \frac{Q}{A} = \frac{\cdot 0107008}{\cdot 0030679} = 3\cdot 48$$

$$\therefore \quad \sqrt{h} = 3\cdot 3 \text{ and } h = 10\cdot 89 \text{ feet.}$$

This is more than the 9 feet allowed, so we must try a larger pipe, say $\frac{13}{16}$-inch, then

$$A = \frac{13 \times 13 \times \cdot 78539}{16 \times 16 \times 144} = \cdot 0036 \text{ sq. feet}$$

$$\sqrt{R} = \cdot 130 \text{ feet as } R = \frac{13}{16 \times 12 \times 4} = \cdot 0169 \text{ feet,}$$

$$\therefore \quad c = 38 \text{ (from Diagram);}$$

$$\text{and } v = c\sqrt{RS} = 38 \times \cdot 13\sqrt{\frac{h}{20}} = 1\cdot 10\sqrt{h}$$

$$= \frac{Q}{A} = \frac{\cdot 0107}{\cdot 0036} = 2\cdot 97$$

$$\therefore \quad \sqrt{h} = 2\cdot 7 \text{ and } h = 7\cdot 29 \text{ feet,}$$

so that a $\frac{13}{16}$-inch pipe fulfils the condition.

To ascertain the actual velocity and discharge at Y with a head of 8 feet, allowing 1 foot for minor losses, then

$$v = c\sqrt{RS} = 38 \times \cdot 13\sqrt{\frac{8}{20}} = 3\cdot 11 \text{ feet per second}$$

$$Q = Av = \cdot 0036 \times 3\cdot 11 = \cdot 011196 \text{ cu. feet per second}$$

$$= 4\cdot 18 \text{ gallons per minute.}$$

We will now ascertain whether the allowance for *minor losses* is enough.

Loss due to two bends, where

$$\frac{d}{2\rho} = 0\cdot3 \text{ (Table 14, page 63),}$$

is as follows :—

$$2\,H_b = 2 \times \cdot000013 \times 90^0 \times 3\cdot11^2 = \cdot023 \text{ feet.}$$

The loss due to reduction of bore from $\frac{13}{16}$-inch to $\frac{5}{8}$-inch for the tap is found as before :—

$$v_1 = \left(\frac{d}{d_1}\right)^2 v = \left(\frac{13}{16 \times 12} \times \frac{8 \times 12}{5}\right)^2 \times 3\cdot11 = 5\cdot25 \text{ feet.}$$

The loss of head to produce this velocity is

$$H_{v1} = \frac{v_1^2}{2g} = \frac{5\cdot25^2}{2g} = \cdot427 \text{ feet,}$$

which includes that due to the ordinary velocity.

The minor losses are therefore :

$2H_b$	=	·023 feet.
H_{v1}	=	·427
Total		·450 feet,

which is less than the 1 foot allowed in the preceding calculation.

To ascertain the size for the supply pipe O_2Z, taking head of pressure at O as 90 feet.

Now the discharge at X	=	2·94 gallons per minute.
Y	=	4·18
The total supply at Z should	=	7·12 gallons per minute.
or	=	·019 cu. feet per second.
The head of pressure at Z	=	28 feet.
,, ,, elevation above O_2	=	10
		38
Head of pressure at O_2	=	90
∴ Effective head	=	52 feet.

Try a 1-inch pipe, and allow 2 feet for minor losses.

$$v = c\sqrt{RS} = 41 \times \cdot144\sqrt{\frac{50}{100}}$$

$$= 4\cdot174 \text{ feet per second.}$$

$$Q = \cdot00545 \times 4\cdot174$$

$$= \cdot02 \text{ cu. feet per second,}$$

so that a 1-inch pipe is near enough.

(b.) To ascertain the discharge of these two pipes separately with a pressure of 90 feet in the main.

First, assuming that the tap at Y is open, and that at X is closed.

We have two different diameters of pipe to deal with :—

Let the effective head at $Z = h$

Then head available for $O_2Z = 90 - 11 - h = 79 - h$, allowing one foot for minor losses

" " " $ZY = h - 19 - 1 = h - 20$

For the 1-inch pipe O_2Z we have

$$Q = Av = \cdot 00545 \times c\sqrt{RS} = \cdot 00545 \times 41 \times \cdot 144\sqrt{\frac{79-h}{100}}$$

$$= \cdot 032176\sqrt{\frac{79-h}{100}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and for the $\frac{13}{16}$-inch pipe

$$Q = Av = \cdot 0036 \times c\sqrt{RS} = \cdot 0036 \times 38 \times \cdot 13\sqrt{\frac{h-20}{20}}$$

$$= \cdot 016784\sqrt{\frac{h-20}{20}} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Compounding (1) and (2) we get

$$\sqrt{\frac{79-h}{100} \times \frac{20}{h-20}} = \frac{\cdot 016784}{\cdot 032176} = \cdot 52$$

$$\frac{79-h}{5(h-20)} = \cdot 2704$$

$$79 - h = 1 \cdot 352h - 27 \cdot 04$$

$$2 \cdot 352h = 106 \cdot 04$$

$$\therefore h = 45 \text{ feet}$$

and for discharge at Y from a $\frac{13}{16}$-inch pipe

$$Q = \cdot 016784\sqrt{\frac{45-20}{20}} \text{ cubic feet per second}$$

$$= 7 \cdot 01 \text{ gallons per minute.}$$

Similarly, for the discharge from X when Y is closed,

Let h = head of pressure at Z, and allowing one foot for minor losses the head available for $O_2Z = 90 - 11 - h = 79 - h$

" " " $XZ = h$

For O_2Z, a 1-inch pipe, we have as before :

$$Q = \cdot 032176\sqrt{\frac{79-h}{100}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and for XZ a $\frac{5}{8}$ inch pipe

$$Q = \cdot 00213 \times 34 \cdot 5 \times \cdot 114\sqrt{\frac{h}{30}}$$

$$= \cdot 008377\sqrt{\frac{h}{30}} \quad . \quad . \quad . \quad . \quad (4)$$

Compounding (3) and (4)

$$\sqrt{\frac{79-h}{100}\times\frac{30}{h}}=\frac{\cdot008377}{\cdot032176}=\cdot263$$

$$\text{or } \frac{3(79-h)}{10h}=\cdot069$$

$$\therefore\ 237-3h=\cdot96h$$

$$\therefore\ 3\cdot96h=237$$

$$\text{and } h=59\cdot5 \text{ feet.}$$

The discharge through the $\frac{5}{8}$-inch pipe from X is thus :

$$Q=\cdot008377\sqrt{\frac{59\cdot5}{30}}=\cdot008377\times1\cdot4$$

$$=\cdot0117 \text{ cubic feet per second}$$

$$=4\cdot37 \text{ gallons per minute.}$$

Mains.

Example VI.

Fig. 53 represents the arrangement of the branch main for the supply of several houses on either side of a road, leading from a main at the end of the road.

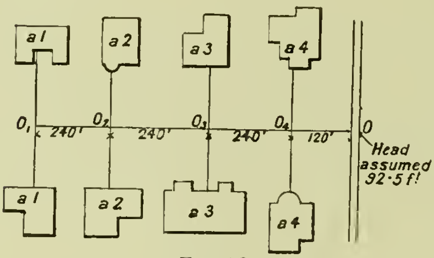


Fig. 53.

A longitudinal section along the road is shown in Fig. 54, giving the bends of the pipes and the highest taps in the houses, the arrangements for the connection of the branch main with the houses being similar to those adopted in the previous example, Fig. 51, being the section from O_2 on the plan to the house a_2.

We will assume one half the taps to be open at the same time

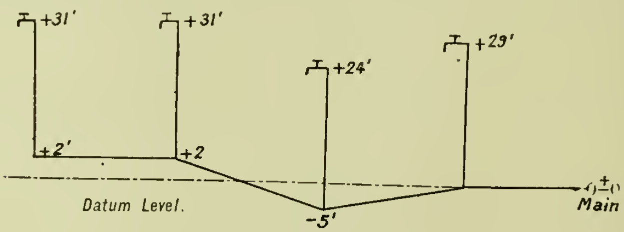


Fig. 54.

e.g., those in the four houses a_1, a_2, a_1, a_2, and that they are taking their full supply.

It is required to find the size of the branch main OO_2 to enable it to supply each house with seven gallons of water per minute. The head of pressure at O_2 with reference to the datum level of the main becomes 90 (head of pressure) + 2 (head of elevation) = 92 feet, and the available head to overcome the resistance in the branch main $OO_2 = 92\cdot5 - 92 = \cdot5$ foot, the head of pressure at O being found to be 92·5 feet.

The delivery at O_2 must be $7 \times 4 = 28$ gallons per minute
$= \cdot07504$ cu. feet per second.

First, employing Darcy and Bazin's formula,

$$S = \frac{h}{l} = \frac{\cdot5}{600} = \frac{1}{1200} = \cdot0008$$

To find (d) approximately:

$$d = 0\cdot2541 \sqrt[5]{\frac{Q^2}{S}}$$
$$= 0\cdot2541 \sqrt[5]{(\cdot07504)^2 \times 1200}$$
$$= \cdot37161 \text{ feet}$$
$$= 4\cdot45 \text{ inches,}$$

so a 5-inch pipe will be necessary.

And $\zeta = \cdot012$ (from Table 47)

$$\therefore d = \sqrt[5]{\frac{Q^2\zeta}{\pi^2 S}} = \sqrt[5]{\frac{(\cdot07504)^2 \times \cdot012 \times 1200}{\pi^2}}$$
$$= \cdot38276 \text{ feet}$$
$$= 4\cdot6 \text{ inches}$$

so that a 5-inch pipe would be required.

Secondly, using Ganguillet and Kutter's formula.

For a lightly encrusted pipe we may take $n = 0\cdot017$.

Assume a 5-inch cast-iron pipe,

then $\sqrt{R} = \cdot332$ (from Table 27, page 86)

and $c = 44\cdot9$ (from Diagram)

$A = \cdot13635$ sq. feet

$\sqrt{S} = \cdot028$, as $S = \cdot0008$

$$\therefore Q = Av = \cdot13635 \times 44\cdot9 \times \cdot322 \times \cdot028$$
$$= \cdot05519 \text{ cu. feet per second}$$
$$= 20\cdot63 \text{ gallons per minute.}$$

This is too little, so we must try a 6-inch pipe,

then $\sqrt{R} = \cdot353$

$c = 48\cdot49$ (from Diagram)

$A = \cdot196349$ sq. feet

$$\therefore Q = Av = \cdot196349 \times 48\cdot49 \times \cdot353 \times \cdot028$$
$$= \cdot0341 \text{ cu. feet per second}$$
$$= 35\cdot17 \text{ gallons per minute,}$$

which is well on the safe side, and thus a 6-inch pipe must be adopted.

Horse-Power.

Example VII.

It is often necessary to ascertain the horse-power required to pump water from a well or other source for the supply of buildings on a higher level. It may be done in the following manner :—

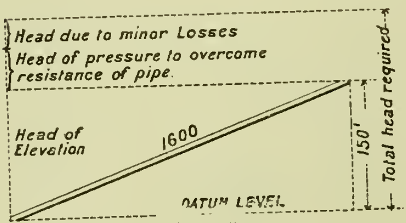


Fig. 55.

We will assume we want to use a 6-inch pipe, and that the length of pipe required is 1,600 feet, involving in its line, three bends of 30°, four bends of 40°, and four of 50° ; the level to which the water has to be pumped is 150 feet above the river where the pumping station is situated (Fig. 55). The velocity is not to exceed 4 feet per second, so as not to put undue duty on the engine.

First of all using Darcy and Bazin's formula.

To determine the head required to overcome the resistance of the pipe we have

$$v = \frac{k}{2}\sqrt{dS} = 4$$

and $k = 74$ (from Table 47, page 105)

$d = \cdot 5$ feet

$S = \frac{h}{1600}$ feet

$A = \cdot 19635$ sq. feet (from Table 28, page 106)

$$\therefore \quad 4 = \frac{74}{2}\sqrt{\cdot 5 \times \frac{h}{1600}}$$

$$\therefore \quad \frac{\cdot 5h}{1600} = \left(\frac{4}{37}\right)^2 = \frac{16}{1369}$$

$$\text{and } h = \frac{16 \times 1600 \times 10}{5 \times 1369} = 37 \cdot 4 \text{ feet.}$$

From Table 16, page 63.—Taking radius of bend as 24 inches

$$\text{then } \frac{\text{radius of bend}}{\text{diameter of pipe}} = \frac{24}{6} = 4$$

Loss of head due to bends :—

$$\text{For } \left.\begin{array}{ll} 3 \text{ bends of} & 30° \\ 4 & 40° \\ 4 & 50° \end{array}\right\} \cdot 000011 \times \left\{\begin{array}{l} 30° \times 3 \\ 40° \times 4 \\ 50° \times 4 \end{array}\right\} \times 4^2$$

For 11 bends $\cdot 000011 \times 450 \times 16$	=	7·92 feet.
Loss of head due to velocity $= \frac{v^2}{2g} = \frac{4^2}{64 \cdot 4}$	=	·248
Head due to minor losses	=	8·168
resistance of pipe	=	37·4
elevation ,,	=	150·0
∴ Total head required	=	195·568 feet.

Volume discharged

$= A \times \text{velocity}$

$= \cdot 19635 \times 4$

$= \cdot 7854$ cu. feet per second

$= \cdot 7854 \times 60$

$= 47 \cdot 124$ cu. feet per minute.

Total weight raised per minute $= 47 \cdot 124 \times 62 \cdot 4$ lbs.

$= 2940 \cdot 54$ lbs. to a height of 195·568 feet

and horse-power required (nominal)

$$= \frac{195 \cdot 568 \times 2940 \cdot 54}{33000}$$

$= 17\frac{1}{2}$, nearly.

Second, we will make the same calculation with Ganguillet and Kutter's formula.

Now for a cast-iron force main we may take $n = \cdot 0128$ and $S = \frac{150}{1600} = \cdot 09375$. Then we must find in the first place the head required to overcome the resistance of the pipe.

$$v = c\sqrt{RS} = \overset{c}{72 \cdot 5} \times \overset{\sqrt{R}}{\cdot 353} \times \sqrt{\frac{h}{1600}}$$ [c obtained from Diagram.]

$$4 = \frac{72 \cdot 5 \times \cdot 353}{40}\sqrt{h} \quad \therefore \sqrt{h} = \frac{160}{72 \cdot 5 \times \cdot 353}$$

$\therefore\ h = 39 \cdot 085$ feet.

To ascertain amount of minor losses.

For the loss due to bends, from the Table 16 on page 63 we get the proportion $\frac{\text{radius of bend}}{\text{diameter of pipe}} = \frac{24}{6} = 4$, where radius of bend = 24 inches, and the multiplier becomes ·000011.

The loss of head due to 3 bends of 30°, 4 of 40° and 4 of 50°

$$= \cdot 000011 \times \left\{\begin{matrix} 30 \times 3 \\ 40 \times 4 \\ 50 \times 4 \end{matrix}\right\} \times 4^2$$

∴ Loss of head for 11 bends $= \cdot 000011 \times 450 \times 16 = 7 \cdot 92$ feet.

Loss of head due to velocity

$$= \frac{v^2}{2g} = \frac{4}{64\cdot4} \qquad = \cdot248$$

Head due to minor losses	=	8·168
resistance of pipe	=	39·085
elevation „	=	150·000
Total head required	=	197·253

Quantity of water pumped

$= \cdot1963 \times 4 = \cdot7852$ cu. feet per second

$= \cdot7852 \times 60 = 47\cdot112$ „ minute

Total weight raised per minute $= 47\cdot112 \times 62\cdot4$ lbs.

$= 2939\cdot79$ lbs. to a height of 197·253 feet

∴ Horse-power (nominal) required

$$= \frac{197\cdot253 \times 2939\cdot79}{33{,}000}$$

$$= 17\cdot57$$

N.B.—It will be noticed in this set of examples that the results obtained by the use of Messrs. Ganguillet and Kutter's formula are safer than those resulting from the employment of the one by Messrs. Darcy and Bazin, and as there is no difficulty in its application, the former formula, viz., that by Messrs. Ganguillet and Kutter, should be invariably adopted in practice. The differences in the results due to these two formulæ would be still more marked had the values of (n), as given in Table 54, page 126, been adopted.

CHAPTER VI.

CONSTRUCTION AND MATERIALS.

Portland Cement.—The only cementing material that should be used where sewage may come in contact with it is Portland cement, as it is practically unaffected by the acids contained in sewage. Portland cement is manufactured on the banks of the Thames and Medway, from an intimate mixture of chalk and river mud obtained from the estuaries of those rivers. Other materials are also employed for the purpose, such as chalk and clay at the works on the Tyne, and blue lias limestone and shale in Warwickshire and Dorsetshire. In every case an endeavour is made to obtain a mixture of clay and lime in the cement after calcination, in which there shall be not less than 35 per cent. of clay and not more than 61 per cent. of lime.

If there is too large a percentage of clay it makes the cement quick-setting, but it does not attain the ultimate strength of slow-setting cement. This is due to its having to be burnt at a lower temperature to avoid vitrifying, which would render the clinker useless. On the other hand, if there is an excess of lime a proportion of it exists as "free lime." A slight excess of lime enables the materials to be burnt at a high temperature, and thus a slow-setting and strong cement is produced. It should be ground very fine and air-slaked, in order to slake the "free" lime, and thus neutralise the dangers involved of excessive and irregular expansion in its use, resulting in distortion and cracks.

The following is the composition of a good Portland cement suitable for engineering work :—

*Alumina and oxide of iron,	not less than	12·0	per cent.
*Silica,	,,	23·0	,,
Lime,	not to exceed	61·0	,,
Magnesia,	,,	1·0	,,
Sulphuric acid,	,,	1·5	,,
Carbonic acid and moisture,	,,	1·5	,,
	Total	100·0	

* These percentages may vary slightly, but taken together should not be less than 35 per cent.

Portland cement with any admixture of Kentish rag, slag, &c., should not be used on important engineering works.

The specific gravity of Portland cement one month after manufacture should not be less than 3·1. There is no difficulty involved in testing it, as it can readily be obtained by the use of one of Mann's gravimeters, or of an ordinary chemical pipette.

The quality of Portland cement is generally judged of by its colour, weight per striked bushel, fineness of grinding, rapidity of setting, behaviour and colour of pats in air and water, and tensile strength of briquettes after definite periods of immersion. The colour of Portland cement when supplied should be a greenish-grey. This may be ascertained by lightly rubbing a very small quantity on a sheet of white paper. The weight is generally specified not to be less than 110 to 112 lbs. to the striked bushel. Great care is required in making the test, and a special hopper should be used for gradually filling the measure, which is then struck off level with the top by means of a straight-edge.

As regards fineness, it is generally specified that 90 per cent. of the cement shall pass through a sieve with 2,500 meshes to the square inch; but it must be remembered that the residue is inert, and acts simply as so much sand in the cement. The quality of Portland cement would, therefore, be much improved by finer grinding, and thus a considerable increase in its cementitious value might be secured at a comparatively small additional cost. Mr. H. K. G. Bamber, F.C.S., in a paper read by him before the Incorporated Association of Municipal and County Engineers in 1892–3, states that if a well-burnt cement were ground to such a state of fineness as for it all to pass through a 50×50 mesh sieve and leave only a 10 per cent. residue on a 76×76 mesh sieve, the increase of cost would be about two shillings per ton; and to still further increase the fineness so that all should pass through a sieve of 12,100 meshes, the increased cost would be six shillings per ton. The corresponding increase in strength of the cement is 37·66 and 90 per cent. more than the strength of a cement ground to leave 10 to 15 per cent. on a 2,500-mesh sieve. The practical advantage is that a smaller amount of cement is required to obtain the same strength, and in the case of concrete the amount of cement might be reduced by 25 and 50 per cent. in the two cases respectively.

Rapidity of setting may be judged with a Vicat's needle, but usually if pats made with the cement can be indented by a slight pressure of a finger-nail at the end of two hours, the cement is considered to be slow-setting.

Contraction.—Two pats of cement about 4 inches in diameter, and three-eighths of an inch thick at the centre and thin at the edges, should be made on pieces of glass, and when set, one should be placed in water. They should not show any cracks or alteration in form whether left in air or water, they should remain of a light grey colour, but if they assume a yellow or ochry tinge, it is an indication of an excess of clay in the composition of the cement. When broken, the pats should appear uniform in colour and hardness throughout the section.

Expansion.—Light glass tubes, such as are used in chemical laboratories and known as test-tubes, should be filled with cement paste, and struck level with the top. The glass tube should remain intact; a fracture of its surface denotes expansion and the presence of an excess of lime. The tensile strength of the cement should also be ascertained by means of briquettes in a suitable machine, such as Michaeli's shot machine (agents, Messrs. Currie & Co., Leith). The tensile strength after being one day in the mould and six in water should not be less than 350 pounds per square inch, and 450 pounds per square inch when fourteen days old.

Mr. Mann, C.E., is of opinion that it is better to test the cementitious strength of cement by using briquettes made with the addition of "standard sand," in the proportion of three of sand to one of cement. After the briquette has been one day in the mould and twenty-seven in water, it should bear from 200 to 250 pounds per square inch. The standard sand is obtained from Leighton Buzzard, and is prepared by passing it through a 400-mesh sieve, and afterwards retaining the portion which will not pass a 900-mesh sieve.

Cement Store-house.—It is a good plan to have a special house built for the purpose, with movable floors clinker-laid, each floor having a vertical space of about ten inches. If each floor is made of such an extent as to hold a day's consumption at the works, and the first load is placed on the top floor and allowed to remain there twenty-four hours, the boards are then turned over, and the cement falls to the second floor; the upper floor is then replenished with cement, and the operation is continued, the cement gradually passing to the bottom floor, where it is ready for use. A passage must be left for the purpose of tilting the boards and manipulating the cement.

Hydraulic Lime.—Blue lias lime may be used for other portions of the work, if it can be obtained freshly ground and of reliable quality, at a cheaper rate than Portland cement, but it must be remembered it will not take as much sand as cement.

Sand.—The sand employed should be sharp and clean, and entirely free from loam or organic matter of any kind. Crushed limestone or well-burnt clay may be used.

Mortar.—The proportions of sand and cement are usually two and a half to one by measure. An excess of water in mixing should be avoided.

For jointing pipes of an ordinary socket pattern, the mortar would consist of one part sand to four parts Portland cement.

Blue lias lime mortar should consist of equal proportions of lime and sand.

Bricks should be dipped in water, and all surfaces where hydraulic mortar is to be applied should be well wetted beforehand.

Grout.—For sealing the great variety of patent pipe-joints now in the market, a grout made by mixing three parts of clear water with five and a half parts of sound Portland cement is suitable. It should be free from lumps, freshly made, and well stirred before it is poured in.

Concrete.—In considering the ingredients for concrete it is best to regard the stone or gravel as the aggregate, with a matrix of mortar composed of sand and cementing material. It is then easier to adapt it to the particular requirements of any case. The aggregate should be angular, and composed of pieces of all sizes, depending on the thickness and description of the work to be done; it should be clean and hard. Broken stone, bricks, gravel, and shingle are used for this purpose. The proportions of the several ingredients depend to a great extent on the size of the pieces, the shape, and quality of the aggregate; the larger the aggregate, the stronger the concrete, as the surface to be covered by cement is reduced. If used for face-work to other concrete, &c., or for a floor, then the smaller the aggregate, the finer the surface of the finished concrete will be. Concrete should be made with carefully proportioned materials, so that the whole of the interstices in the aggregate may be thoroughly filled with mortar, and the latter so constituted that every grain of sand is covered with a film of cement. Eor large works the proper proportion should be arrived at by experiment, as to the voids to be filled in each case; or it may be judged of from the results of local experience and the quality of the work required for the special case involved. Where Thames ballast, which consists of gravel mixed with sand, is used, a good proportion is one part by measure of cement to six parts by measure of ballast. The latter should be gauged first, and then spread out in a layer, the cement being distributed over the surface; it should then be turned over twice in a dry state on a clean shovelling-board, and then again turned over three times after the water has been added by means of a rose. A better way, when the sand is separate from the broken stone or gravel, is to work it into a mortar with the cement, and, after well wetting the aggregate, to spread the mortar evenly over the flattened heap, and then to turn both over together twice. In this way a more even distribution of the cementing material is effected, and a proportionally better concrete obtained, with a less amount of shovelling. Cement mortar or concrete which has set should not be broken up and used except as ballast, and any set surface should be thoroughly cleaned and wetted before an additional layer is put on, so as to ensure perfect cohesion. Another proportion for making concrete is four parts of broken stone that will pass a 2-inch ring, and three of sand to one of Portland cement. Concrete should not be over-rammed, as there is a tendency for the cement to be brought to the surface in the operation. This is especially the case when, as usual, there is an excess of water. If the concrete is well trodden down and worked in with a spade, but little else should be required, as the surplus water forces out the interstitial air. Some engineers, however, insist on the concrete being well punned, and in that case the amount of water used in mixing must be strictly limited. Cement in making concrete requires about four gallons of water to each cubic foot of concrete.

Bricks.—These should be of the best quality procurable in the locality, with a hard, impervious surface ; and if the local bricks are not sufficiently good for facing, a salt-glazed or blue Staffordshire brick had better be obtained.

Description of Pipes used.— Glazed stoneware pipes, circular in section, are in general use for drains. They should be made of a superior description of clay, highly vitrified and salt-glazed in a kiln, so as to render the pipe impervious to water. The pipes should be perfectly smooth inside, and free from defects, especially on the interior, accurate in form, and perfectly straight, with well-formed sockets, and an even thickness of material throughout. All stoneware pipes intended to be used for foul drains should be specially selected, and capable of withstanding a pressure of twenty-five feet of water without showing signs of sweating.

Many manufacturers supply a special class of pipe, in which every length has been thoroughly examined and tested to a considerable head of water, and stamped with the maker's name and the word "tested," before being sent from the works. Only "tested" pipes should be used for conveyance of sewage.

Stoneware "Tested" Pipes, Strength of.—The following Table shows the results of experiments by David Kirkaldy & Son to ascertain the resistance to thrusting stress of three stoneware drain-pipes supplied by Mr. George Jennings. The pipes were bedded according to their standard system, and having been previously tested for soundness, were subjected to a pressure of fifty feet of water ; they showed no signs of leaking.

TABLE 60.

Description.	Test No.	Dimensions.			Ultimate Stress.		Stress per Foot Run.	Appearance of Fracture.
		Mean Thickness.	Dia. Outside.	Length Parallel Outside				
		inch.	inches.	inches.	lbs.	lbs.	lbs.	
Internal diameter 9 ins.	EE							
Length of bore 24¼ inches.	41	·92	10⅞	22¾	3,908		2,061	Light Buff Uniform.
Length of bore 24¼ inches.	42	·92	10⅞	22¾	3,617	3,655	1,908	Do. Do.
Length of bore 24½ inches.	40	·92	10¾	23	3,440		1,795	Do. Do.

Maximum Diameter 18 Inches.—Stoneware pipes should not be used of greater diameter than 18 inches, and if laid at an unusual depth, say 15 to 20 feet, or in soft clay or any unstable ground, an extra thickness of pipe should be employed, or it will be necessary to strengthen them with a surrounding of concrete, to resist the pressure.

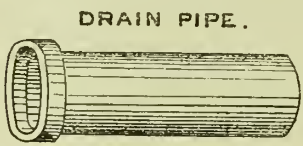


Fig. 56.

Thickness of Glazed Stoneware Pipes.—Pipes of 12 inches in diameter or greater should be at least one-twelfth their diameter in thickness. The ordinary thickness of stoneware pipes (Fig. 56) is as follows :—

Internal diameter.			Thickness of Material.
3 inches	...	...	½ inch.
4 "	...	...	⅝ "
6 "	...	...	¾ "
9 "	...	...	1 "
12 "	...	..	1⅛ "
15 "	...	...	1¼ "
18 "	...	...	1⅜ "

They are made in 2-feet 3-inch lengths over all up to a diameter of 9 inches, beyond which the lengths are 2 feet 9 inches ; the sockets take up 3 inches at one end, so that the actual length of a 2-feet 3-inch pipe when laid is only 2 feet.

Pipes are now being made 3 feet long to save joints, but this is only practicable for the larger diameters.

Forms.—Channel pipes, junctions, bends, taper pieces (Figs. 57—60), and syphons (Fig. 225) are made for each description of stoneware pipe. Pipes should never be cut to form junctions, and the connection between pipes, &c., of different diameters should always be effected by the use of proper "taper" pieces ; *vide* Fig. 61.

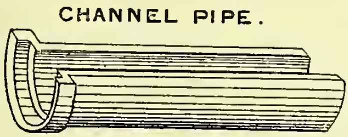


FIG. 57.

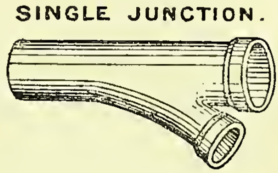


FIG. 58.

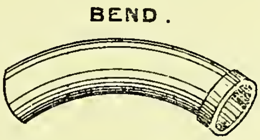


FIG. 59.

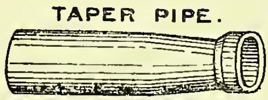


FIG. 60.

Messrs. J. Cliff & Sons manufacture stoneware pipes 2 feet 6 inches long to order, the following table giving particulars :—

TABLE 61.

Diameter of Pipe in Inches.	Thickness of Pipe in Inches.	Depth of Socket in Inches.	Weight of Pipes in Pounds.
4	$\frac{5}{8}$	$1\frac{3}{8}$	$16\frac{1}{2}$
6	$\frac{3}{4}$	2	$31\frac{1}{2}$
9	$\frac{7}{8}$	$2\frac{1}{4}$	58
12	1	$2\frac{1}{4}$	88
15	$1\frac{1}{4}$	$2\frac{3}{8}$	143
18	$1\frac{1}{2}$	$2\frac{1}{2}$	209

"**Granite Stoneware Sanitary Pipes.**"—These pipes are manufactured by the Albion Clay Co., who state that specially selected and blended clays (not fire-clay) are employed, so as to ensure an *impervious* body well adapted for sanitary purposes, and that consequently the pipes have a toughness as opposed to brittleness, which is a valuable qualification.

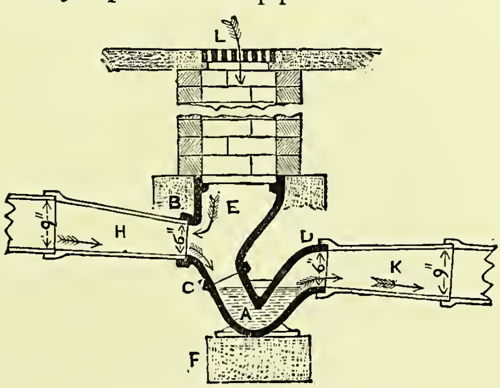


FIG. 61.—Section of a 6-in. Syphon with diminishing-pipes and air-shaft.

The Company claim that the pipes are true in line and section, highly glazed, smooth, incorrodible, and imperishable.

and have withstood the highest tests made by Messrs. Kirkaldy and other authorities at home and abroad.

The following table gives particulars of their ordinary socket pipes :—

TABLE 62.

									Length of Pipes, Feet.
Size of pipes	2	3							2
Approximate number of yards to the ton	200	130							
Size of pipes	4	5							2 & 2′ 6″
Approximate number of yards to the ton	90	70							
Size of pipes	6	7	8	9	10	12	15	18	2 2′ 6″ & 3·0
Approximate number of yards to the ton	54	43	36	30	26	18	12	8	
Size of pipes	21	24	27	30	36				3
Approximate number of yards to the ton	6	4							

The Albion Clay Co. also manufacture "granitic stoneware" pipes 3 feet long, with Sykes' patent joint. The particulars are given below :—

TABLE 63.

Diameter of Pipe in Inches.	Thickness of Pipe in Inches.	Depth of Socket in Inches.	Weight of Pipe in Yards to Ton.
9	$\frac{3}{4}$	3	24
12	1	3	15
15	$1\frac{1}{4}$	$3\frac{1}{2}$	8
18	$1\frac{1}{2}$	$3\frac{1}{2}$	6
21	$1\frac{3}{4}$	4	$4\frac{1}{2}$
24	2	4	3

Special Connections.—Thos. Kemp makes some special connections (Figs. 62—66) for house drainage which enable rods to be passed through the whole of the drains to the main sewer in the road from the ground surface. The advantages claimed for their use are that they obviate the necessity for building expensive manholes to inspect or unstop the drain, and that consequently deep cuttings are only required for the main drain.

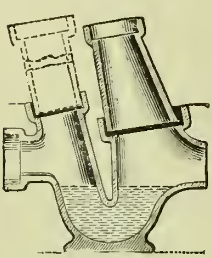


Fig. 62.—Kemp's Interceptor.

The Standard Access Pipes, Traps, and Bends are made with the same object in view as those already referred to. The diameter at the bends is made larger than usual, so as to enable the rod to be passed round the angle (*vide* Fig. 67, page 208), guides being provided in order to divert the rod. The figure shows an Access Pipe as fixed to a sewer, with a 9-inch pipe shaft leading up to the ground level. It is provided with

Mooney's patent expansion cover, which may be either hinged or loose. As will be seen, the top pipe is without a socket, and fits inside the iron

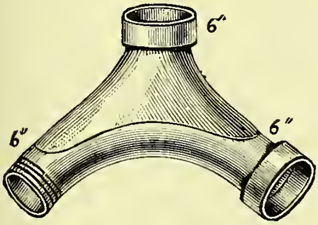


FIG. 63.—Sweeping eye bend.

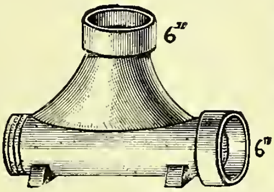


FIG. 64.—Sweeping eye pipe.

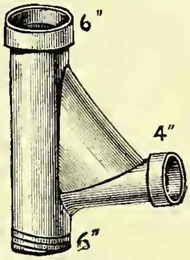


FIG. 65.—Sweeping eye junction.

cover, which may be set upon a flag or other support. When heavy traffic passes over the cover there is no pressure on the upright shaft.

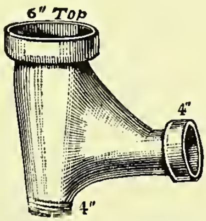


FIG. 66.—Sweeping eye taper junction.

"Loco" Inspection Shaft.—An inspection shaft in connection with a "Loco" intercepting trap is shown in Fig. 68. This arrangement is useful where manholes cannot be afforded.

Concrete Pipes.—When larger sewers than 18 inches diameter are required, concrete pipes may be used up to 36 inches diameter.

Messrs. Henry Sharp, Jones & Co., of Poole, Dorset, make most excellent rock-concrete pipes (Fig. 69), which can be advantageously used in many instances, and are gaining ground in popularity with engineers. Messrs. Bowes, Scott & Western, of Broadway Chambers, Westminster, are the London agents.

The manufacturers state that these tubes are made of a very dense and heavy concrete, the result of careful selection and combination of the most suitable materials, manipulated by processes best calculated to secure the utmost value, both of the matrix and the aggregates employed.

The cement used, and the concrete made, are subject to stringent and constant tests, constituting such safeguards that it is impossible for any but the most reliable material to be incorporated in the manufacture.

They are silicated by the Victoria Stone Company's patent process. The following advantages are claimed for them :—

By using rock-concrete tubes, sewers can be constructed with economy and rapidity.

They are imperishable.

They bed well in a trench, having no projecting socket.

They form a perfectly true barrel.

They permit of a water-tight joint being easily made.

They consequently make a water-tight sewer.

They are especially adapted for sewer work, inasmuch as their great strength, hardness, and durability are enhanced by the action of water and sewage.

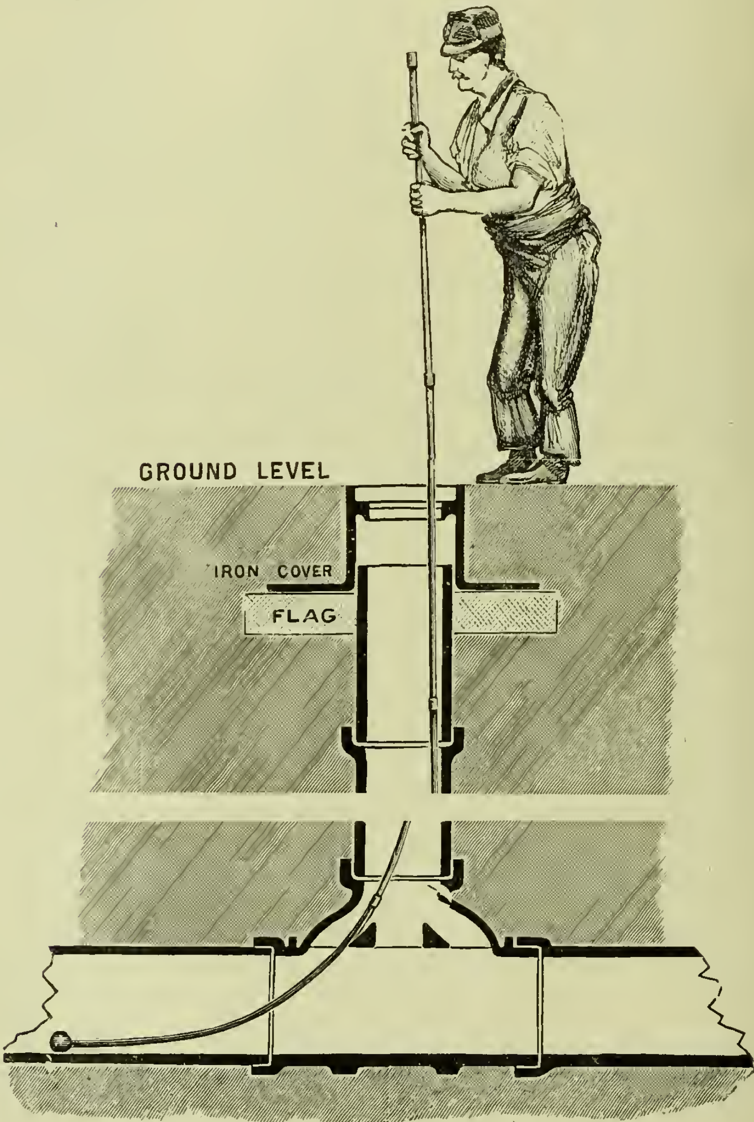


Fig. 67.—Access pipe as fixed to sewer, with 9-inch pipe shaft.

Junctions with sockets for stoneware pipes are kept in stock.

Half tubes can be supplied for irrigation purposes, and have been so used.

Sizes.—The following sizes are kept in stock :—

TABLE 64.

Size.	Thickness.	Price per Foot Run.	Size.	Thickness.	Price per Foot Run.
		s. d.			s. d.
12 inches.	$1\frac{1}{8}$ inch.	1 6	24 inches.	$1\frac{5}{8}$ inches.	4 3
15 "	$1\frac{1}{4}$ "	1 10	" "	2 "	5 3
18 "	$1\frac{1}{2}$ "	2 9	27 "	$2\frac{1}{4}$ "	6 3
21 "	$1\frac{5}{8}$ "	3 9	30 "	$2\frac{1}{4}$ "	8 0
			36 "	$2\frac{1}{2}$ "	10 0

Egg-shaped in Segments for Linings.

3 feet 3 inches by 2 feet, and 2 inches thick.

Joints: How Made.*—Pipes for conveying sewage should have their joints set in pure cement to prevent leakage. With ordinary socket joints, as shown in Fig. 70, page 210, three or four strands of tarred gasket should be used to centre the pipes and to prevent the cement from exuding from the inner edge of the joint. Each joint should be carefully examined on the inside, and any cement that may have come through should be smoothed off before the next length of pipe is laid, so as not to leave any obstruction to the flow of sewage.

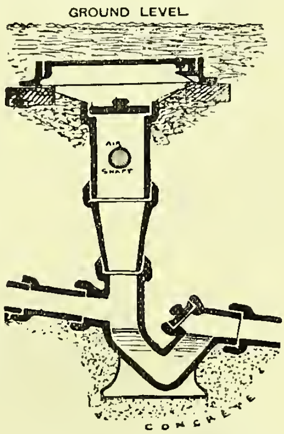


FIG. 68.—"Loco" Inspection Shaft, with Intercepting Trap.

The joints of pipes set in cement cannot be readily opened for examination without clearing a considerable length of the drain, and breaking, at any rate, one of the pipes.

Saddle-joints.—To obviate this, pipes with saddle-joints were, at one time, much used, but they are objectionable, as it is very difficult to make the joints of the saddles water-tight without using cement, and then, of course, the advantage gained by their use is lost, for the pipe would have

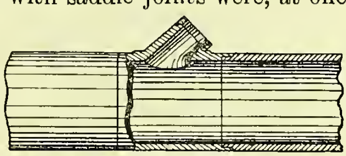


FIG. 69.—Rock-concrete Pipe.

* The practice of employing clay as a jointing material for pipes to convey foul water cannot be too strongly condemned : it is, however, still continued in some places, even of importance. Drains so laid will not stand the water test—the clay washes out of the joints after a time, and during dry weather the liquid portion of the sewage runs into the subsoil, diminishing the flushing power. On the other hand, after rain, subsoil water is discharged through the drain, thus interfering with its carrying capacity for sewage proper ; the dangerous nature of the sewer-gases is greatly intensified by those given off by the decomposing sewage in the subsoil. The water supply through leaky mains is also endangered.

to be broken, as is ordinarily the case. The saddles are also found to give way under pressure.

When a drain is carried under a wall, an opening supported by a strong lintel should be left clear of the pipe, so that the settlement

JOINTS IN EARTHENWARE PIPES.

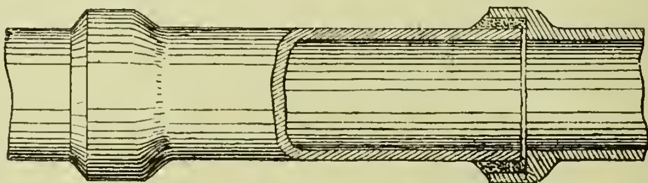


Fig. 70.—Gasket and Cement.

(which takes place to some extent in all buildings) may not produce any pressure on the pipe tending to break it.

Stanford's joint (Fig. 71) is similar in construction to turned spigot and faucet joints of cast-iron pipes, being formed of turned rings of a cheap and durable material adhering firmly to the pipe, and securing a mechanical fit inside the sockets and around the spigot end of the pipe. These rings, which are slightly spherical in shape, fit

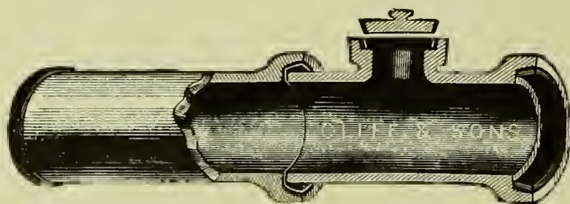


Fig. 71.—The Stanford Joint.

exactly into each other, being counterparts, and in order to allow of a little play of the pipes, the sockets are formed slightly concave, and the spigot ends convex to a similar extent. The rings are made of a composition of ground earthenware pipes, sulphur, and tar. The joint is formed by either painting, tarring, or greasing the surfaces, and by giving a twist to the pipe to fit them closely together. The joints can be taken asunder without breaking the pipe.

The manufacturers claim that this joint is preferable to a cement joint where there is any liability to settlement, as its soundness also is not impaired either by expansion or contraction.

In sewer work in bad or wet ground, the joint can be readily made with this description of joint.

These pipes are manufactured by Joseph Cliff & Sons, Doulton & Co., Oates & Green, and others.

Button's Patent "Secure" Joint.—This joint is represented in Fig. 72. On the spigots and in the sockets of the pipes a bituminous material is cast by means of a patented apparatus. In these cast rings grooves are formed, as shown in the drawing, so that when the spigot of

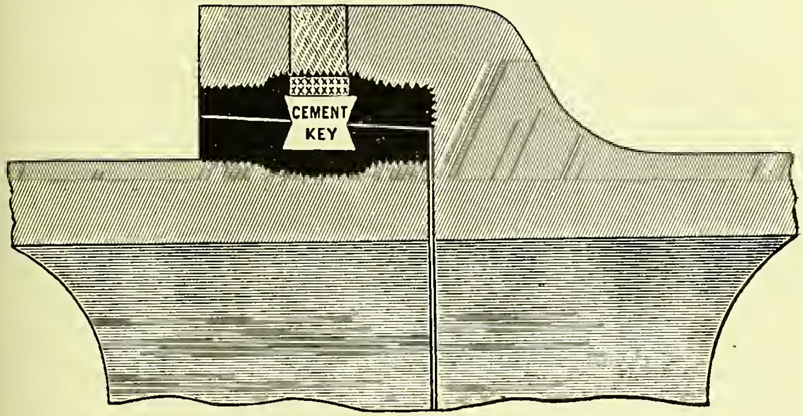


Fig. 72.—Button's patent "Secure" Joint.

the pipe is placed in the socket an annular groove is obtained, into which cement is run, so as to seal the joint. The cast rings have true bevelled surfaces, which allow of easy fixing, and when the groove has been

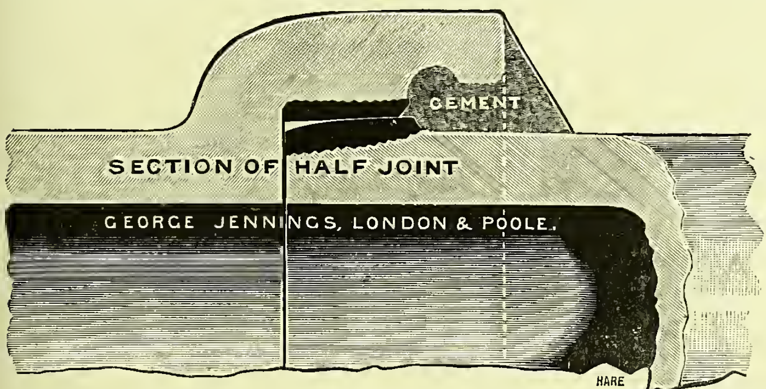


Fig. 73.—The Double Seal Joint.

filled with cement, the key thus formed makes the joint water-tight. The following are the advantages claimed for this joint:—

1st. A reliable and secure water-tight joint is obtained.

2nd. There is no possibility of the spigot drawing from the socket, as is sometimes the case with ordinary bituminous joints.

3rd. The continuous rings of bituminous material in socket and on spigot in combination with the annular key of cement ensure a water-tight joint being made.

4th. Pipes provided with the "Secure" joint can be laid, and the joints properly made in sewer trenches, when there is a continual stream of water running through.

5th. The "Secure" joint being prepared by specially made and patented apparatus, a true alignment of pipes when laid in position is ensured.

These pipes are supplied by J. Duckett & Sons.

The Double Seal (Tyndale's Patent) (Fig. 73, page 211) is similar to the Stanford jointed pipes, but has in addition a deeper and undercut socket,

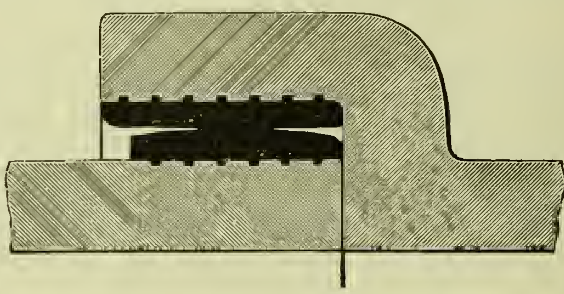


Fig. 74.—The Self-adjusting Joint.

so that after the pipes have been laid and tested, a fillet of cement may be placed all round the joint so as to secure it. It is claimed for these pipes that the arrangement secures a rigidity equal to that of the ordinary cemented joint, and, in addition, the concentric fitting of the pipes

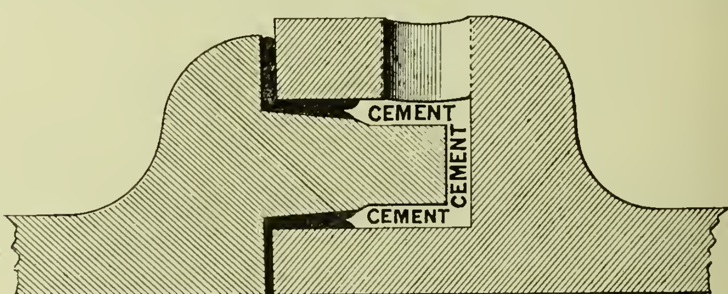


Fig. 75.—The Archer patent Joint.

is ensured; the pipes can be quickly laid and tested; there is no fear of any obstruction being caused by cement being squeezed up inside the pipe.

These pipes are made by Mr. George Jennings.

Doulton's Self-adjusting.—Another form of joint is that known as Doulton's patent self-adjusting joint (Fig. 74); no cement is required, and it is supposed not to be injured by any settlement.

The Archer improved patent joint for stoneware pipes is represented in Fig. 75.

The following is the description of the mode of laying the Archer jointed pipes, as given by the manufacturers :—

A flat band of plastic compo or well-tempered clay is pressed against the face of the inner and outer flanges at the base of the tongue while the pipe is on end, the tongue itself remaining undressed to come directly in contact with the liquid cement. The tongue end so dressed is tapped home into the groove-end with an iron bar against a block of wood at the opposite end of the pipe, until the outer flanges nearly meet. In some cases the outer band of clay is pressed between the flanges after the pipes are laid. After each pipe is tapped home, the interior frill of clay in the joint is removed by a half-circle rake, or by pulling, with a connecting cord passed through the pipes during the process of laying, a sack packed with shavings to the full diameter of the pipe.

In starting to lay a length of pipes, the first pipe should be stayed or fixed at the end, so as to resist the tapping or levering home of the next pipe. After a number of pipes have been joined, pour the cream of cement (three of pure Portland cement to two of water) into one of the holes in the socket, having first placed a cup of clay round each of the two holes to give the cement a "head." The barrier thus left in the socket between the two holes prevents the cement running both ways round the joint.

Leave unfilled the last joint made in a length, to be dealt with when another length has been driven home. In preparing the bed for these pipes, sufficient earth should be cleared away from the front of the socket to enable the flanges of the tongue of the next pipe to go clear home ; and also a hollow made for the socket of the other end, so that the body of the pipe will rest on the bottom of the trench. In pouring in the cement a can or vessel with a spout should be used. In laying these pipes in moving sand, a small pit should be made in front of the socket, so that the sand will run into it instead of into the socket ; but any small quantity of sand in the socket does not interfere with the making of a sound joint, as it commingles with the cement.

Pipes tested and marked "T" are sold at 10% (per cent.) extra on quoted price.

Hassall's Improved patent Safety Pipe-joint is made in several varieties.

The "Single-Lined" variety is shown in part section in Fig. 76. The object of casting on the rings for Hassall's joint is more particularly to centre the pipes and to retain them in the desired position while the final operation of running in the Portland cement is being effected ; the cast rings are not intended to come into contact with each other, but to have between them a cushion of plastic cement to receive and imbed and render harmless any grit which may be in the way, and which should fill up any flaw in the castings and, besides, make a water-tight joint whilst the Portland cement in the second joint is setting.

Another variety of the Hassall joint is shown in Fig. 77. In this case

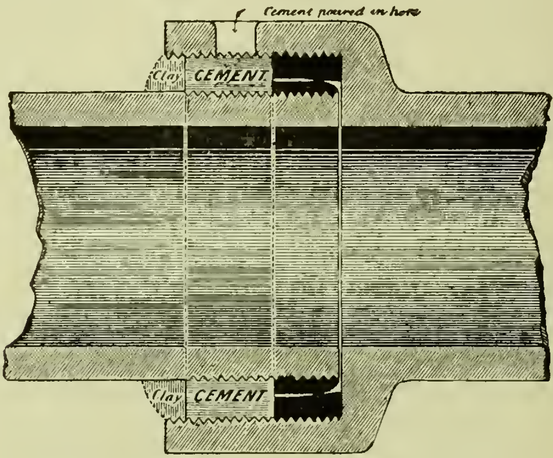


Fig. 76.—Hassall's Safety Pipe-joint, Single-lined.

also-plastic cement is used, in the first place so as to make a tight joint on either side of the groove left in the joint where the spigot end is in its proper position in the socket; this groove is afterwards filled in with

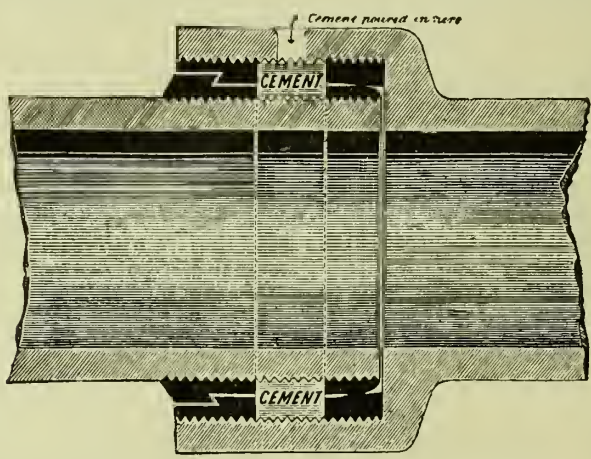


Fig. 77.—Hassall's Safety Pipe-joint, Double-lined.

liquid Portland cement. Pipes with these joints can be obtained from Messrs. Parker & Hassall, Brougham Chambers, Nottingham. Pipes with the Hassall's patent Safety Joint are being extensively used by Mr. W. B. G. Bennett, C.E., in the new drainage works at Southampton.

Green's patent True-invert Pipe is shown in cross and longitudinal sections in Fig. 78. The object of this patent is to form a perfectly level bottom or invert, to strengthen the socket at its weakest point, and to make a triple joint in a cheap and effective manner, and while allowing for a slight settlement when first laid, to form an absolutely rigid

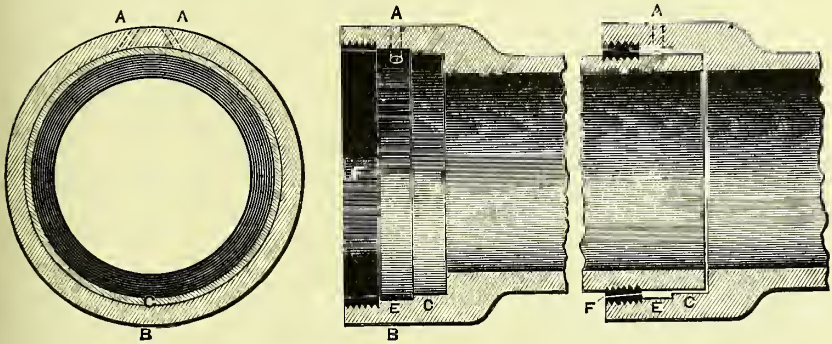


FIG. 78.—Green's True-invert Pipe.

joint directly the cement sets. These pipes are manufactured by Messrs. Oates & Green, Limited.

Patent **Paragon** Pipes, as made by the Albion Clay Co., Limited, are shown in Fig. 79; they vary principally in depth of sockets. The sockets are made eccentric to the pipe, and the depth of the shoulder in the socket

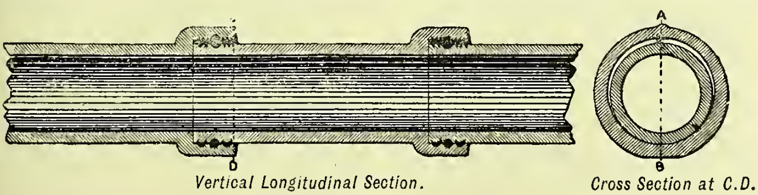


FIG. 79.—The Paragon Pipe (C form).

at the invert is equal to the thickness of the pipe, so that when the spigot is inserted and abuts at the shoulder, it rests on the socket, and has a solid bearing thereon, and cannot drop, and thereby forms and maintains a true invert at the joints even though the pipes should through any cause be disturbed.

The "Loco" Drain-joint.—Fig. 80 is a simple invention for facilitating making joints water-tight with cement, besides ensuring a true invert. The socket is of undercut form, and has within it two projections on which the spigot end of the next pipe rests, and which level the whole of the pipe-ends so as to form a true invert and avoid the objectionable step forming an obstruction as commonly found. The annular undercut space is filled with cement, and as the cement sets the slight increment which it assumes during process of setting tightens the cement in the socket automatically. A water-tight joint is thus easily

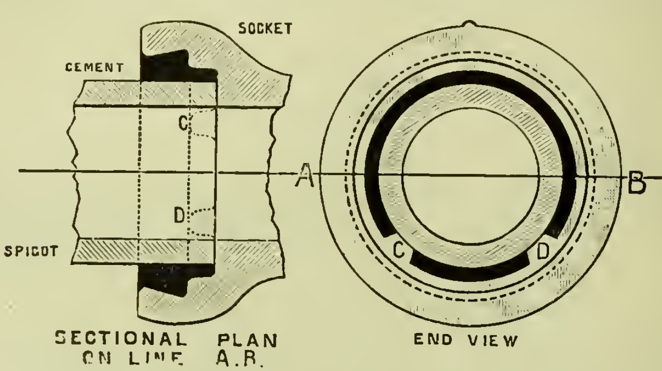


FIG. 80.—The "Loco" Drain-joint.

made. The cost of these pipes is only slightly in excess of ordinary pipes.

The Ames and Crosta Pipe-joint.—*Single Seal Joint.*—This pipe-joint is represented in Figs. 81 and 82. The socket is made rather deeper than usual, and is provided with a specially-formed sealing-

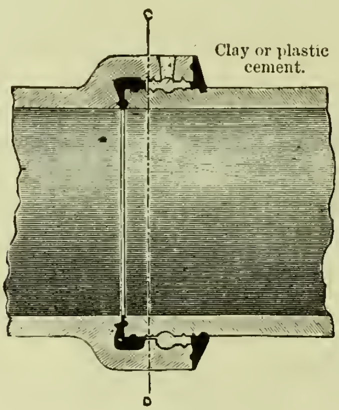


FIG. 81.—Ames and Crosta's Single Seal Pipe-joint.

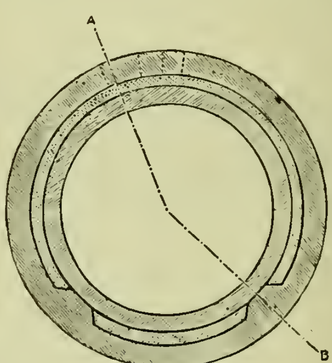


FIG. 82.—Section of same.

chamber at the seat, so constructed that the jointing material displaced from the sealing-chamber by the spigot on insertion is prevented from entering the pipes, and is forced into grooves formed on the spigot, thus sealing the junction of the pipes at the seat of the socket. Studs or rest-pieces are formed midway in the socket, to ensure a true alignment of the invert. When jointing the pipes, the sealing-chamber at the seat of the socket should be filled with clay, plastic cement, or other jointing material, as far as the inner edge of the central rib. The spigot should then be forced into the sealing-chamber, displacing the jointing material and filling the grooves on the spigot. A fillet of the same jointing material should then be worked round the entrance of the socket, and the joint grouted up through the running hole with cement. Another method of completing the joint is to make it with stiff cement in the ordinary way.

Double Seal (Fig. 83).—The special Double Seal Joint for water-logged ground has, as far as the seat in the socket is concerned, a sealing-chamber similar to that for the Single Seal Joint, the socket being made slightly deeper, and a collar is formed on the spigot end of the pipe, with a sealing-chamber of the same pattern as the one at the seat of the socket. A running-in hole and rising hole are formed in the socket, so that the space between the two sealing-chambers may be grouted up with liquid cement. When making the joint in this case, the jointing material is filled into both sealing-chambers before introducing the spigot. Care should be taken to lay the pipes with the "dart" on the top, as this mark so situated indicates that the pipes are correctly laid.

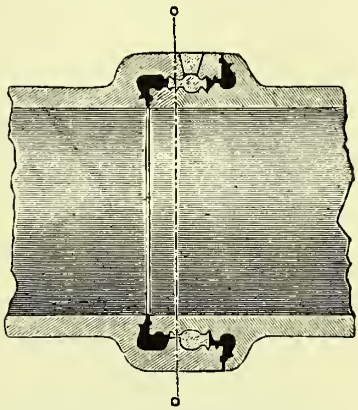


FIG. 83.—Ames and Crosta's Double Seal Pipe-joint.

The following are some of the special advantages claimed by the manufacturers :—That the pipes are made of the very best stoneware, well glazed, and perfectly true in every part ; that there are no composition rings to damage in transit and to increase the cost of the pipe ; the joints are made with the most reliable and cheapest jointing materials ; a self-adjusting and true alignment of the invert is ensured and maintained even when ordinary workmen are employed ; whilst the initial cost of the pipes with these joints is very little more than that of an ordinary pipe.

These pipes are made of the following lengths :—

TABLE 65.

Diameters of Pipe. Inches.					Lengths.		Thickness.
					Ft. Ins.	Ft. Ins.	
2	3	4	5	6	2 0	—	Approximately one-tenth the diameter of the respective sizes.
	7	8	9	10	2 0	2 6	
	12	15	18	21	2 6	3 0	
	24	27	30	36	3 0	—	

TABLE 66.—APPROXIMATE DEPTHS OF SOCKETS.

Diameters of Pipes.	2	3	4	5	6	7	8	9	10	Inches.
Single Seal Joint	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{3}$	$2\frac{3}{4}$	$2\frac{3}{4}$	3	3	Depth in Ins.
Double ,, ...	$2\frac{3}{4}$	$2\frac{3}{4}$	3	3	$3\frac{1}{4}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{3}{4}$	

Diameters of Pipes.	12		18	21	24	27	30	36	Inches.
Single Seal Joints.........	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{3}{4}$	4	4	4	Depth in Ins.
Double	4	4	$4\frac{1}{4}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	

Sykes' Patent Joint (Fig. 84).—This joint is designed to make water-tight sewers in water-logged ground. On the spigot and in the socket of each length of pipe male and female screw threads are formed of a bituminous composition, in such a manner as to afford a certain amount of play in adjusting the joint, and secure the requisite amount of flexibility without interfering with the level of the invert of the

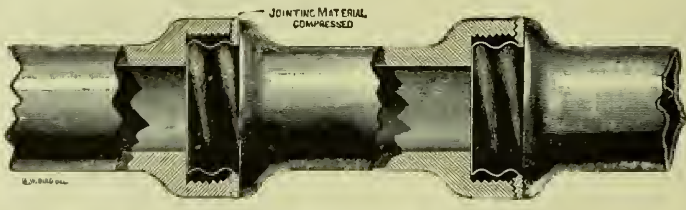


FIG. 84.—Sykes' patent Joint.

sewer. The spigot is also provided with a strong collar or rim, against which, when jointing the pipes, a fillet of cement composition is placed, which is compressed between the end of the socket and the rim by the act of screwing the pipes together. The pressure involved forces the superfluous cement composition into the space left for play in the thread, thus forming an effectual seal. It is claimed that this cement composition has superior advantages to Portland cement, being water and acid resisting, slightly elastic, and imperishable. It is mixed on the works, and is applied in a mastic condition about the consistency of ordinary glaziers' putty. It is said that these pipes have stood a hydraulic test of 140 pounds on the square inch ; they are manufactured by the Albion Clay Co., of all sizes up to twenty-four inches in diameter, and in any lengths up to three feet.

Constructing Drains, &c.: Preliminary Arrangements.—It is very essential that the pipes should be laid straight and true, with a perfectly regular gradient. This can only be ensured by the use of "sight-rails" and "boning-rods." Sight-rails consist of two strong uprights with a stiff, straight edge or rail (Fig. 85) fixed horizontally between them at right angles to the proposed line of pipe or culvert. The levels of the rails are so arranged that the difference in level between any pair of rails

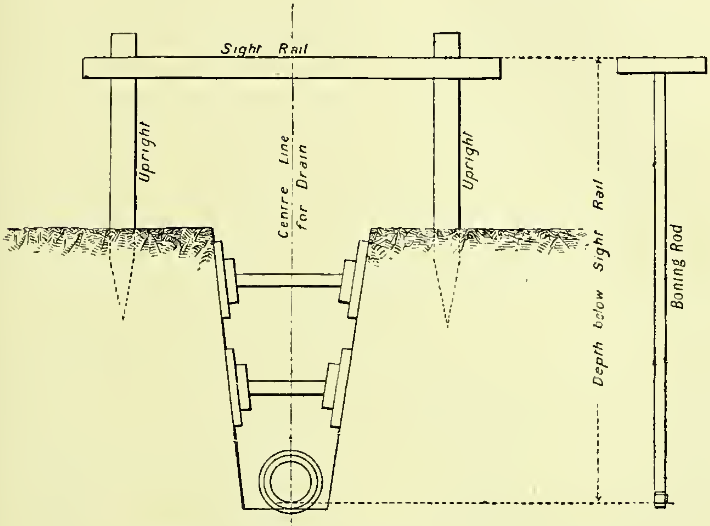


FIG. 85.—"Sight-rails" and "Boning-rods" for laying Drain Pipes.

corresponds to the fall to be given to the pipe in the distance between their positions, the actual height of the rails above the ground being sufficient for convenient observation; thus an imaginary line of sight

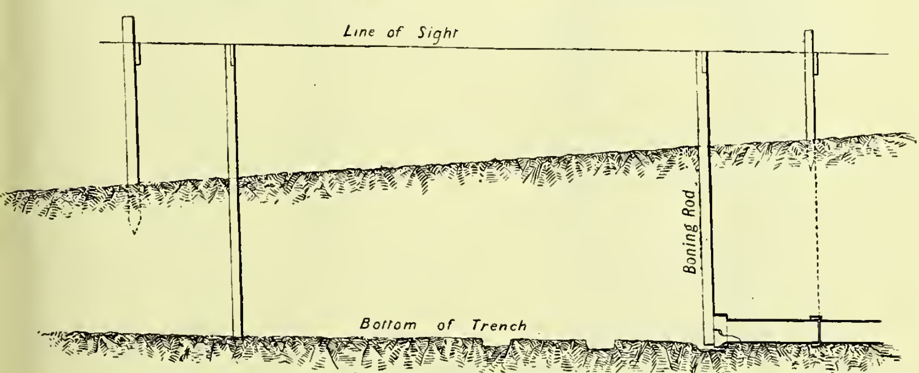
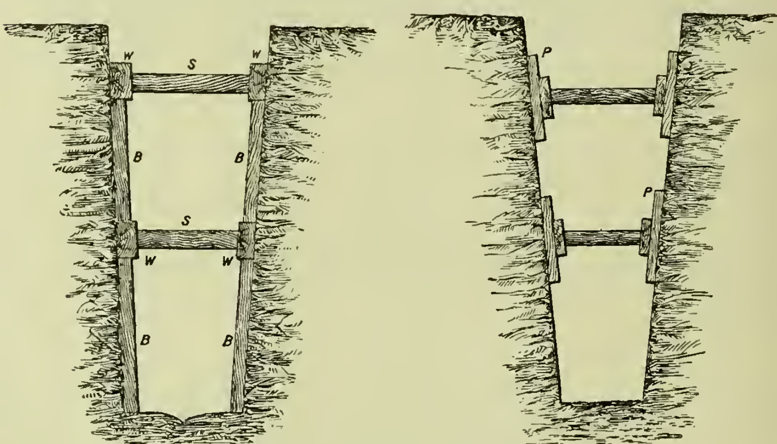


FIG. 86.—Preparing bottom of Trench for laying Drain Pipes.

(Fig. 86) is established parallel to the invert of the proposed drain. In connection with the sight-rails, a boning-rod, with a staff the same length as the difference in level between the sight-rail and the invert of the pipe to be placed immediately below it, is required; the head of the staff consists of a cross-bar like a T-square. If now the boning-rod is held vertically and moved between the sight-rails so that the top edge of the head of the boning-rod is kept in the line of sight, and moved along the line between the two sight-rails, the lower end will give the line of levels for the invert of the drain. A small wooden bracket should be fixed at right angles to the foot of the boning-rod, to rest on the invert of the pipe, so that the distance from the top of the crosshead to the underside of the bracket marks the actual difference in level required between the line of sight and the invert. The feet of the uprights are secured either by driving the sharpened ends into the ground, or by placing them in pipes stood on end and filled with sand well pressed down. It is advisable to employ three sight-rails for each length of pipe, to avoid mistakes.

The sight-rails should be securely fixed on firm ground which will not be disturbed by the progress of the excavation; and if the substratum is peaty, or such as will shrink under pumping, so as to lower the subsoil water, special care must be taken that the sight-rails, or bench-marks to be worked to, are placed in such positions as to remain unaffected, or the result will be a crippled sewer—that is, the grade and line will not be true.

Excavating Trenches.—The trench should not be wider than necessary to admit of the pipe-layer working conveniently at the



FIGS. 87 and 88.—Methods of Shoring Trenches.

bottom. The length of trench to be opened at one time must depend on circumstances, but for testing purposes it is better to extend the trench to the section between two manholes; but this may have to be modified if the ground is of an unstable nature from wet sand or other causes. If the trench passes close to buildings or walls so as to endanger the foundations, then it would be advisable to keep it open for as short a time as possible: the trench would then have to be got out in short lengths. Where the excavation exceeds three lifts in depth, say 16 feet, it may be found cheaper to drive a heading, but in this case very close supervision is necessary. Tunnelling may also be resorted to when rock is met with which will afford a sufficient thickness over the trench to resist the superincumbent weight. The width of the trench at the top depends on the nature of the rock or soil in which it is cut, and the method of shoring adopted. One of the simplest methods for shoring a trench is shown in Fig. 87. The trench in this case is cut rather wider at the top than at the bottom, so that the timbering, if it slips at all, tightens up against the sides of the trench. The horizontal "walings" (W) are kept in position by struts (S). Props (B) are sometimes added. In Fig. 88 an addition is shown of short boards behind the walings, called "poling-boards" (P), which are usually $1\frac{1}{2}$ inches in

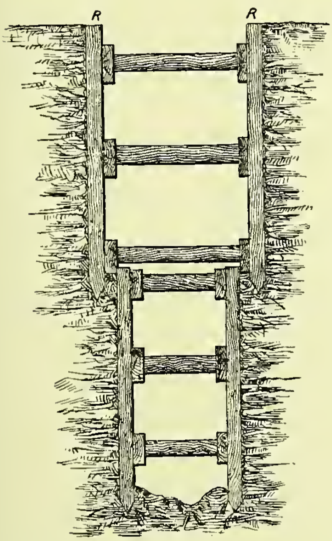


FIG. 89.—Method of Shoring Trenches in bad ground.

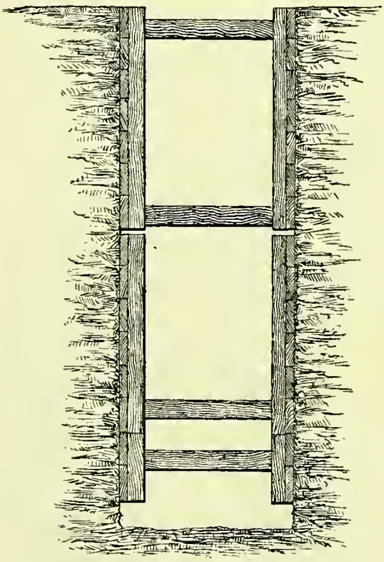


FIG. 90.—Another method of Shoring a Trench.

thickness, and are intended to afford support to a larger surface of the side of the trench than the walings do alone. If the ground is bad, the walings and struts are used, but instead of poling-boards "runners" (R) (Fig. 89) are employed. The walings are made with 9-inch by 3-inch spruce planks, and the struts or stretchers of good square or round fir; in narrow trenches, of larch. The runners are formed of spruce or elm 9 inches by $1\frac{1}{2}$ inches, cut into 3-feet 6-inch lengths, and have the points sharpened. so that they may be driven down behind the walings. The width of the top of the excavation when made in this manner must be sufficient to allow of the requisite number of tiers of runners being used to get the required depth.

The shoring should be sufficiently strong to support safely the weight of the staging and the material thrown on to it by the workmen, as well as the workmen themselves. The height of a lift is usually from 4 to 5 feet.

The struts should be of as great a diameter as possible, as if small in proportion to the width of the walings there is a tendency to split them. If half-round timbers are used for shoring, the flat side should be placed against the side of the trench, and the ends of the struts bird's-mouthed to fit round the side of the walings.

If the ground is very loose and of the consistency of running sand, the runners must be driven close together, and litter, ashes, or other suitable material packed in behind the runners or poling-boards. Should this prove insufficient to prevent the sand from running through, it may be necessary to employ a second row of runners inside and covering the joints of the first row. In difficult ground the work may have to proceed by "settings"—that is, for the space occupied by the timber within each length of walings, filling one in as the next setting is being excavated.

Another method of timbering a trench is shown in Fig. 90. Instead of the runners horizontal sheeting-boards are used, so that the boards can be added as the excavation proceeds; they should be at once supported by short poling-boards and struts. When five or six boards have been inserted, longer poling-boards can be added, and some of the former struts dispensed with.

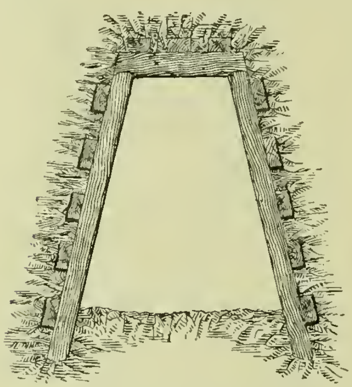


Fig. 91.—Section of Framing for good ground.

In larger excavations heavy timbers, such as whole baulks, and short piling may have to be employed, and then bracing will also be required to keep the timbers in their place, and the whole to be well wedged up.

The bottom of the trench should not be taken below the level required to bed the pipes, unless they are to be laid on a concrete bed. Any inequalities, however, should be filled in with concrete, as otherwise there will be a tendency to subsidence. Mr. T. E. Coleman, surveyor Royal Engineer Civil Staff, is of opinion that all foul-water drains should be laid on a bed of concrete, four inches thick on ordinarily firm and solid ground, and six inches thick where the ground is loose, wet, or marshy. The concrete bed should be twelve inches wider than the bore of the pipe, and after the pipe has been laid and tested, the sides should be haunched up with concrete to a height of half the diameter of the pipe. In order to avoid having to cut spaces in the concrete for the sockets of the pipes, it is desirable to employ wooden moulds six inches wide by two inches deep, and in lengths the full width of the concrete bed, to insert in it flush with the surface at a distance of two feet from centre to centre, or more, corresponding to the effective lengths of the pipes to be used.

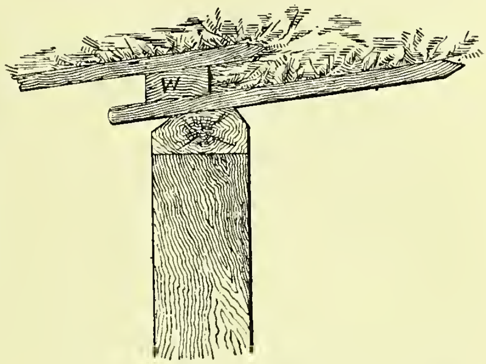


FIG. 92.—Section of Poling-boards or Staves.

When driving galleries or tunnelling, only timber of good quality should be used; it should be hard and tough. Fir is ordinarily used in the construction of small tunnels for sewerage works, for the sills and posts. If the ground is good and firm, the side posts may be sunk a few inches into the bottom of the tunnel to afford lateral support, as in Fig. 91, the poling-boards or staves being placed at the back of the framing. In order to protect the roof from falling in, poling-boards or staves (Fig. 92) are driven in over the capsill, slightly diverging outwards, so that one set overlaps the preceding set, a wedge (W) being inserted between them to facilitate the driving of the next set. If the ground is unstable, a more elaborate framing must be resorted to; *vide* Fig. 93, in which the feet of the side posts are represented resting on a sleeper. An additional lintel and side frame (F) is also employed to support the poling-boards or staves (S), whilst wedges are inserted

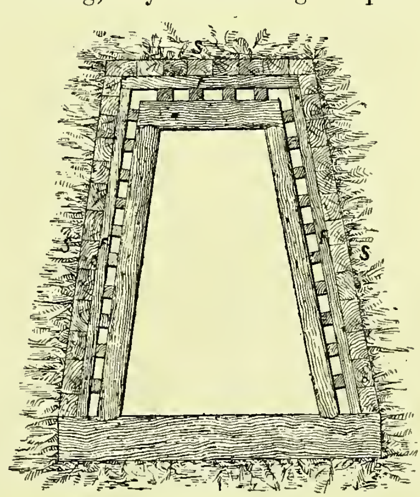


FIG. 93.—Section of Framing for unstable ground.

between the two sets of framing in order to afford the necessary support. In this case the staves are driven close together.

Pipe-laying.—Pipes must be laid at such a level as to enable them to drain the lowest basements of the houses, and the minimum depth over the pipes is five feet where wheeled traffic over them has to be encountered; but when carried under paving, a less depth may be used, the minimum being twice the diameter of the pipe.

The pipes must always be laid with the socket facing up against the direction of the current; they should, therefore, be laid starting from the lower end of the drain and working upwards. *Vide* Fig. 86, page 219.

The ground under each socket should be hollowed out so as to allow the body of the pipe to have a firm bearing, and to give space for the hand to form the lower part of the joint. The individual lengths of pipe are laid and jointed one after the other.

Pipes should be laid by means of a mason's line to ensure their direction being kept perfectly true and uniform throughout their whole length, and plummed down from the central line marked by notches on the sight-rails.

Any cement exuding from the joints on the inside should be carefully removed by passing a small straight-edge up each pipe after jointing, and scraping the surface of the joint; or a disc of a slightly less diameter than the pipe may be used and drawn forward after making each joint. Another method is to keep a plug formed of a sack filled with sawdust or shavings in the portion already laid, and by means of a lath attached to it, to draw it past each joint as made, thus brushing off all superfluous cement which would interfere with the discharge of the pipes.

The "Loco" Drain Badger.—A very useful and practical instrument for clearing away the "overplus" of cement (Fig. 94) from the joints on the inside of the pipes is the "Loco" drain badger (Fig. 95). It consists of two hard wood discs each grooved to receive two india-rubber rings. The two discs are mounted loosely upon a flexible steel

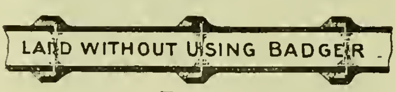


Fig. 94.

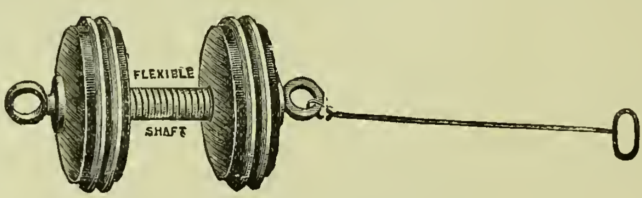


Fig. 95.—The "Loco" Drain Badger.

shaft, which has the property of bending in any direction, enabling it to be pulled round bends. The badger is placed within the first pipe laid, and the next pipe is passed over the handle of the badger; the joint is then made, and the badger pulled forward, cutting off the cement (Fig. 96) without smearing the inside surface of the pipe. The "Loco" drain badger has also been found useful in clearing a drain of sand and filth after the rods have been used, and also to ascertain whether the drain has been truly laid and is free from obstruction of cement.

It is made in 4, 6, and 9-inch sizes, though larger sizes can be made to order, and fresh india-rubber rings supplied when required. The apparatus is supplied by Mr. F. C. Lynde, C.E.

Refilling Trench.—Drainage works should never be covered in until they have been tested and passed by a properly qualified officer; the hydraulic or water-test being applied, as described in Chapter XIII., as soon as the cement has properly set, the necessary head of pressure of five feet being obtained by temporarily fixing a bend and two lengths of pipe. Any defective joints or pipes discovered by water exuding from them should be made good by bedding them in strong concrete. They should then be tested again, and not passed until the work is found to be thoroughly satisfactory. The water should not be discharged from the pipes until the "filling-in" is completed, in order to ascertain that the pipes are not damaged in the process.

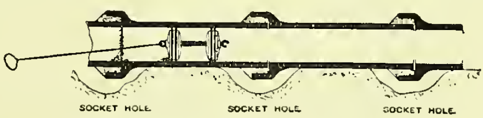


FIG. 96.—Showing Badger in Pipe.

In refilling the trench it is most important that only the smallest of the stuff previously excavated be thrown in first, so that the spaces between the sides of the trench and the pipes may be well filled up, and thus assist in supporting the pipes by filling in the hollows that would otherwise exist. This should be done up to the level of the middle of the pipes, the remainder of the filling being carried out in layers six inches in depth. After a depth of two feet of filling over the pipes is reached in this way, each layer should be well rammed before another is deposited. Large clods of earth and stones should never be thrown in, as the shock occasioned by their fall tends to injure the joints of the pipes, and in the case of culverts, etc., to distort the section.

Ramming need not be carried out with either sand or clean gravel; the best means of consolidating the former is to wet it, whereas the latter will settle of itself; clayey gravel, or gravelly clay, should always be rammed.

Causes of Breakage of Stoneware Pipes.—Drains formed of stoneware pipes get broken through attention not having been paid in their construction to the following points:—

Pipes should not be laid on a rigid foundation without making a recess to take the sockets, so as to ensure an even bearing; and if in rock, they should be bedded in soft material, such as fine gravel or puddled clay.

Pipes should not be laid on a foundation which is liable afterwards to yield, or settle, without taking special precautions—*e.g.*, providing a firm foundation of (say) six inches good concrete.

Pipes should not be laid at too great a depth without protecting them by concrete, or in other ways, to resist the pressure of the material resting on them ; a sudden settlement will often crack or crush a pipe, if the filling in over and around it has not been properly done.

Drain-pipes are also sometimes found to be broken in consequence of accidental or wilful injuries, so that careful inspection and testing should be applied before the trench is filled in, and afterwards also, if possible.

When pipes are laid at a lower depth than usual they should be protected, especially when subjected to heavy traffic ; a weight falling on the surface will otherwise often crack or crush a pipe.

If the joints are weak or defective in any way, the pressure may fracture the pipe, consequently care in selection is very necessary.

Causes of Chokage.—Drain-pipes are also liable to fail by getting choked, and this will, as a rule, be found to be due to some of the following causes :—

The pipe not being properly currented, and consequently not having a sufficient flush to prevent deposit.

Failure of the joints to retain the liquid, which thus escapes, leaving the solids behind.

Badly designed bends and junctions, leading to deposit, as they check the current.

Improper articles being introduced into the drain are a fruitful source of chokage.

It may also be the result of the sewer having been crushed in by the superincumbent weight.

Temporary Obstruction : How Removed.—A temporary obstruction in a small-sized sewer may be speedily removed by the use of drain-cleansing apparatus (Fig. 97), which can be most conveniently worked in connection with manholes. It consists of bamboo cane rods capable of being screwed together, and is very similar to that used by a sweep, but is provided with suitable attachments (Figs. 98—106) for the special purpose. By its use the necessity for opening the ground and breaking the pipe is, to a great extent, avoided.

The drain can in this manner be cleared on either side to 200 feet, or further.

A small wheel is screwed on to the end to enable the rod to be forced over obstructions, and if the obstruction cannot then be removed, its position can be ascertained, and the ground opened at the right spot.

In the case of syphon traps, a temporary obstruction may be cleared by plunging, *i.e.*, by using a tool called a plunger, which consists of a wooden handle about 1½ inches in diameter, to which is fixed at one

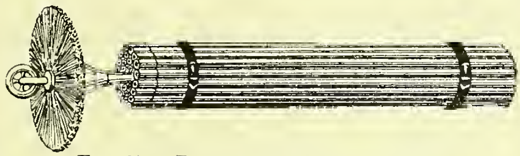


FIG. 97.—Drain Cleansing Apparatus.

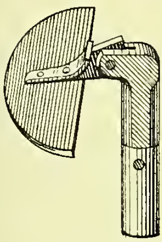


FIG. 98.—Jointed Scraper.

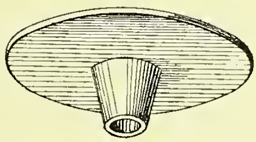


FIG. 99.—Round Scraper.

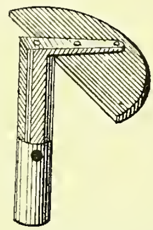


FIG. 100.—Half-round Scraper.

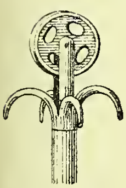


FIG. 101.—Grappling Iron.

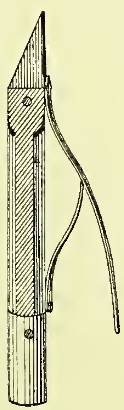


FIG. 104.—Spring Hook.

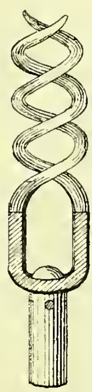


FIG. 105.—Double Worm Screw.

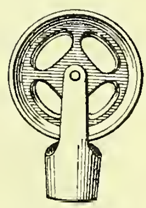


FIG. 102.—Clearing Wheel.

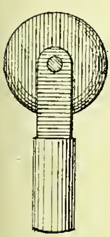


FIG. 103.—Solid gun-metal Clearing Wheel.

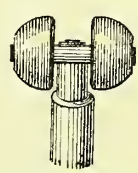


FIG. 106.—Universal Clearing Wheel.

FIGS. 98—106.—Drain Cleansing Fittings.

end a disc of stout leather (⅜-inch thick) of slightly larger diameter than the bore of the syphon. The trap should be first filled with water, and the tool applied and worked up and down like a piston. A mop may be used in a similar manner, as a temporary expedient, or preferably a vulcanised india-rubber plunger, such as the suction and vacuum pump, or Champion Drain Cleaner, as shown in action in Fig. 107. It is supplied by Mr. A. T. Cooper.

Drains of Larger Capacity.—Where drains of larger capacity than can be readily provided by pipes are required, culverts have to be built.

They are usually built in brickwork, in cement mortar, and sometimes in concrete. Some engineers prefer the latter, as Portland cement resists the action of the sewage better than brickwork. If constructed of the latter material, the surface should be rendered in pure Portland cement to a perfectly smooth face, and, in the case of brick culverts, the rendering should be carried up to at least one-half their depth.

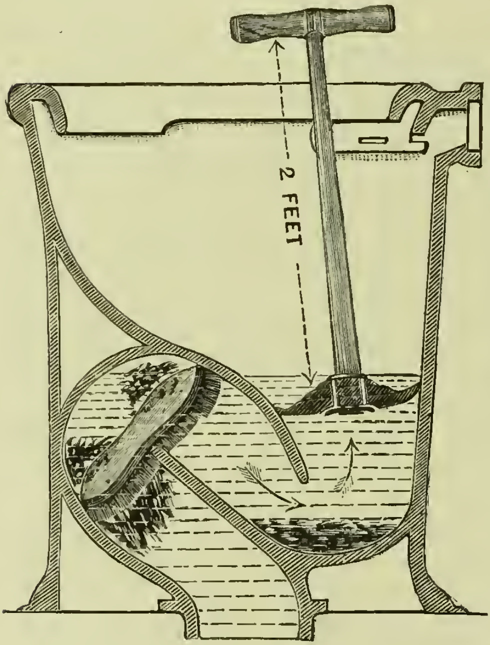


Fig. 107.—Cooper's Drain Cleaner.

Bricks for Sewers.—The best bricks for sewers are those that are hard, well burnt, and absorb the least moisture.

The following classification shows degrees of suitability of different varieties, viz. :—

(1.) The best and most suitable are blue Staffordshire, Shropshire, and those from Buckley (North Wales).

(2.) Those made from fire-brick and terra-cotta clays—more especially when glazed on the surface exposed to the erosion of sewage.

(3.) Gault bricks.

(4.) Any tough and well-burnt brick, not absorbing more than one-sixth its weight of water. On no account should under-burnt, or perforated, brick be used. Bricks need not be rejected for mere roughness of face, provided they be otherwise uniform in size and shape, and they may be used in the crown of the sewer, or in the outer ring, if more than one ring of brick is used. They should, however, never be set in the invert, as considerable friction would occur with sand, stones, and other materials that are generally rolled or carried along with the flow of sewage.

All bricks for use in sewers should be specially made to a given radius, for if ordinary shaped bricks be used, wide open joints will occur in the outer periphery and admit of the percolation of sewage, etc., unless a quick-setting cement is used. The ordinary tests applied to such bricks are for ascertaining their hardness, absorption, power to resist crushing, and freedom from lime.

Doubtful bricks may be tested by soaking them in water, and afterwards exposing them to frost ; or where the temperature will not admit of this, they may be first weighed dry, then steeped in a strong solution of sulphuric acid for seven days, and afterwards, when dry, reweighed.

If no loss of weight occurs, and the brick is otherwise unaffected by the sulphuric acid, it may be safely used.

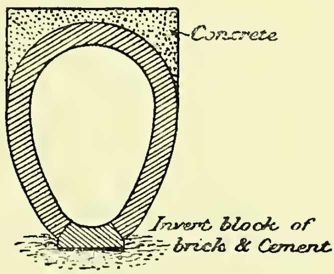


Fig. 108.—Section of Sewer with Hood of Concrete.

Egg-shaped Sewer.—Some of the forms of egg-shaped sewers may be obtained from Chapter IV., Figs. 42, 43, and 44, pages 66 and 67.

Thickness of Brickwork for.—In order to ascertain the thickness of the brickwork required, let d = depth of the excavation in feet, and r = the external radius of the sewer in feet; then the thickness of the brickwork in feet $= \frac{dr}{100}$.

As a general rule, the thickness of brickwork in circular or oval sewers, in cuttings not exceeding 20 feet in depth, and in good ground, the greatest internal dimensions not exceeding three feet, should be $4\frac{1}{2}$ inches ; between three feet and six feet the thickness should be nine inches ; and above six feet, and under nine feet, the brickwork should be 14 inches thick.

When the ring is only $4\frac{1}{2}$ inches thick, a hood of concrete, as shown in Fig. 108, should be laid over for its protection.

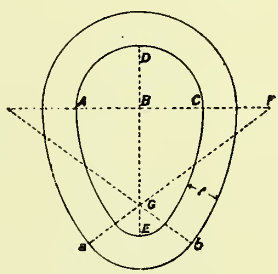


Fig. 109.

Sectional Area and Amount of Brickwork for.—The following formula for finding the sectional area of an egg-shaped sewer and the number of cubic yards of brickwork for lineal yard is due to C. E. Hawkins, Esq., of the Government Geological Survey :—

I. To find the area of the figure A D C E (Fig. 109), which represents the interior of an egg-shaped sewer of the usual proportions, *i.e.*, A C : D E : : 2 : 3.

Let A B $= r$, and let θ denote the angle B F G. Let A = the area of the figure.

$$\therefore A = \frac{\pi r^2}{2} + 2\left\{\frac{(3 r)^2 \theta}{2} - \frac{3 r^2}{2}\right\} + \left(\frac{\pi}{2} - \theta\right) \cdot \left(\frac{r}{2}\right)^2$$

$$= \frac{\pi r^2}{2} + r^2 (9\theta - 3) + \frac{r^2}{4}\left(\frac{\pi}{2} - \theta\right)$$

$$= r^2 \left\{\frac{\pi}{2} + 9\theta - 3 + \frac{\pi}{8} - \frac{\theta}{4}\right\}$$

$$= r^2 \left\{\frac{5\pi}{8} + \frac{35\theta}{4} - 3\right\}. \qquad \text{(i.)}$$

Now θ is the circular measure of the angle B F G, *i.e.*, of 36°·87, since $\tan. \text{B F G} = \frac{\text{B G}}{\text{B F}} = \frac{3}{4}$

$$\therefore \theta = \frac{\pi \times 36^\circ{\cdot}87}{180}$$

substituting] this value for θ, and for π its value 3·14159, we have from (i.),

$$A = r^2 \left\{\frac{5 \times 3{\cdot}14159}{8} + \frac{35 \times 3{\cdot}14159 \times 36{\cdot}87}{180 \times 4} - 3\right\}$$

$$= r^2 \times 4{\cdot}5941$$

$$= r^2 \times 4{\cdot}6, \text{ since the difference is not appreciable.} \qquad \text{(ii.)}$$

The area of an egg-shaped sewer is therefore found accurately by squaring the radius of the top and multiplying this by 4·6.

II. To find the sectional area of the brickwork inclusive of the invert.

Let S = the sectional area, and let t = the thickness of the brickwork.

$$\therefore S = \frac{\pi (r+t)^2 - \pi r^2}{2} + 2\left\{\frac{(3 r+t)^2 \theta}{2} - \frac{(3 r)^2 \theta}{2}\right\} +$$

$$\left\{\left(\frac{r}{2}+t\right)^2 . \left(\frac{\pi}{2} - \theta\right) - \left(\frac{r}{2}\right)^2 . \left(\frac{\pi}{2} - \theta\right)\right\}$$

$$= \frac{\pi}{2}(2 r t + t^2) + \theta (6 r t + t^2) + \left(\frac{\pi}{2} - \theta\right).(r t + t^2)$$

$$= \pi t^2 + r t \left\{\frac{3 \pi}{2} + 5\theta\right\}$$

$$= \pi t^2 + r t \left\{\frac{3 \pi}{2} + \frac{5 \times \pi \times 36{\cdot}87}{180}\right\}$$

$$= \pi t \{t + (r \times 2{\cdot}5241\dot{6})\}$$

$$= 3{\cdot}14159 \times t \{t + (r \times 2{\cdot}5241\dot{6})\}. \qquad \text{(iii.)}$$

The sectional area thus found, when expressed in square yards, will give the number of cubic yards of brickwork in the sewer per lineal yard.

III. The sectional area (s) of the invert $a\,b$ may be found separately, thus:

$$s=\left\{\left(\frac{r}{2}+t\right)^2.\left(\frac{\pi}{2}-\theta\right)\right\}-\left(\frac{r}{2}\right)^2.\left(\frac{\pi}{2}-\theta\right)$$

$$=(rt+t^2)\ .\left(\frac{\pi}{2}-\theta\right)$$

$$=(rt+t^2)\ .\left(\frac{\pi}{2}-\frac{36{\cdot}87\times\pi}{180}\right)$$

$$=(rt+t^2)\ .\left(\frac{53{\cdot}13\times\pi}{180}\right)$$

$$=t\ (r+t)\times{\cdot}9273 \text{ nearly.} \qquad \text{(iv.)}$$

The sectional area thus found, when expressed in square yards, will give the number of cubic yards of brickwork in the invert per lineal yard.

The following Table is intended to show the results of the formulæ, whilst it gives the sectional areas, etc., of all sizes of egg-shaped sewers likely to be constructed. The cubic contents of the brickwork have been calculated from (iii.), and include the inverts. The cubic contents of the inverts alone may be found from (iv.), and deducted from the amounts given in the Table if it be desirable to do so in any particular case.

The areas and quantities have been computed to the nearest decimal.

TABLE 67.

r.	Dimensions of Sewer in Inches.	Area of Sewer in Sq. Feet.	Brickwork in Cubic Yards per Yard Run.		
			4½-inch work.	9-inch work.	13½-in. work.
Inches.					
6	12 × 18	1·150	·214	·527	
7	14 × 21	1·565	·242	·582	
8	16 × 24	2·044	·269	·637	
9	18 × 27	2·587	·297	·692	
10	20 × 30	3·194	·324	·747	
11	22 × 33	3·865	·352	·802	
12	24 × 36	4·600	·379	·857	
13	26 × 39	5·400	·407	·912	
14	28 × 42	6·261	·434	·967	
15	30 × 45	7·187	·462	1·022	
16	32 × 48	8·178	·490	1·077	
17	34 × 51	9·232	·517	1·132	
18	36 × 54	10·350	·545	1·188	
19	38 × 57	11·532	·572	1·243	
20	40 × 60	12·778	·600	1·298	2·094
21	42 × 63	14·087		1·353	2·176
22	44 × 66	15·461		1·408	2·259
23	46 × 69	16·898		1·463	2·342
24	48 × 72	18·400		1·518	2·424
25	50 × 75	19·965		1·573	2·507
26	52 × 78	21·594		1·628	2·589
27	54 × 81	23·287		1·683	2·672
28	56 × 84	25·044		1·738	2·755
29	58 × 87	26·865		1·793	2·837
30	60 × 90	28·750		1·848	2·920
31	62 × 93	30·699		1·903	3·002
32	64 × 96	32·711		1·958	3·085
33	66 × 99	34·788		2·014	3·168
34	68 × 102	36·928		2·069	3·250
35	70 × 105	39·132		2·124	3·333
36	72 × 108	41·400		2·179	3·415

Some Methods of Construction.—The shape of the culvert is generally formed by means of centering, composed of ribs and lagging, and made in two halves, corresponding to the invert and arch. After the excavation of the trench, if invert blocks are employed, the centering is placed in position resting on them ; but where no invert blocks are used, as is

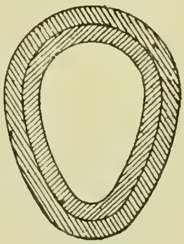


Fig. 110.

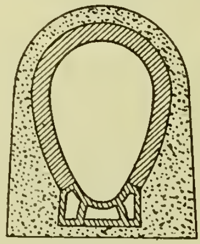


Fig. 111.

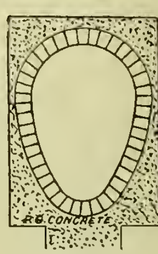


Fig. 112.

Sections of Sewers, showing different methods of construction.

generally the case with concrete culverts, pickets are driven and left projecting above the bottom of the trench a distance equal to the proposed thickness for the concrete below the invert. The centres rest

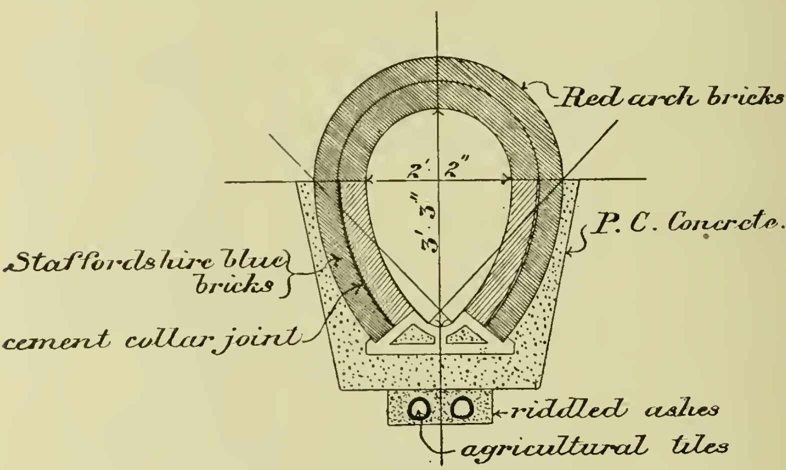


Fig. 113.—Section of Sewer in wet ground.

on the heads of the pickets. The sewer is built in short lengths, and the centering moved forward as the work progresses. Where pickets are used as above, they would be driven down, and the holes made good with pure Portland cement after the concrete has set. Figs. 110, 111, and 112 show a variety of methods of construction.

Egg-shaped Sewers at Southampton, Construction of.—The egg-shaped sewers now being laid in connection with the new scheme of main sewerage for Southampton are shown in Figs. 1—4, Plate XIa.

They were designed by Mr. W. B. G. Bennett, A.M.I.C.E., the borough engineer, to suit the particular formation, viz., gravel in which they are constructed.

The form of egg-shaped sewer adopted is that known as the "New Egg-shaped," and the construction shown has been found to be most suitable to the requirements of the case.

Details of Construction.—The invert blocks employed are made of blue Staffordshire ware, and are made solid with only small perforations, as shown in the Figures, to ensure proper burning throughout and prevent twisting and warping; the invert blocks are also provided with a rebate-joint, as in Fig. 113*a*; they thus differ from ordinary blocks which, as stated on page 233, are generally made with large hollows and have plain straight joints. The advantage of the rebate is that it enables a continuous invert to be obtained, and the block being solid is less liable to fracture from any pressure to which it may be subjected; thus the work is much more durable.

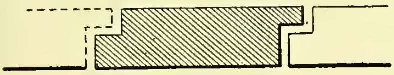


FIG. 113*a*.

Centering.—The following system was adopted for moulding the outer concrete core: light ribs of wrought T-irons were provided to the radii required, as shown in Fig. 113*b*. These T-irons were fixed six to eight feet apart on the invert blocks, and at the back one and a half inch deal battens were placed up to the springing level of the covering arch. The iron ribs and one and a half inch deal battens were removed after moulding the concrete core, the four and a half inch invert was then built against the internal face of the concrete core, a thin jointing of cement being used at the back to fill up irregular places, etc. In order to ensure the internal face of the invert being laid perfectly true, secondary iron ribs to the radii of the internal face of the brick invert were provided; these secondary ribs formed the profile or mould for the bricklayers to construct the invert up to the springing of the covering arches, and also afforded supports for the drums or centres for the construction of the covering arches, the rings of which were turned separately, the first on the centre, and the second over the first ring. The drums or centres for this purpose were ordinary semicircular wooden drum centres.

The whole arrangement worked very simply in practice, and admitting as it did of easy fixing and adjustment, a true form for the inside of the culverts was secured. The whole of these sewers are now nearly completed, and have been found to be perfectly water-tight.

Pipe Drains.—Hassall's pipes were used where a smaller cross-section could be given to the sewer; various sizes of these pipes, from nine inches to eighteen inches in diameter, are shown in Figs. 5—7, and

Figs. 9 and 10 (Plate XIA) as laid in concrete. The section of a special iron pipe, which is laid underneath the railway, and bedded in concrete, is shown in Fig. 8. All these pipes are intended for foul water drainage.

Surface Water Drains.—The greater length of the new surface water

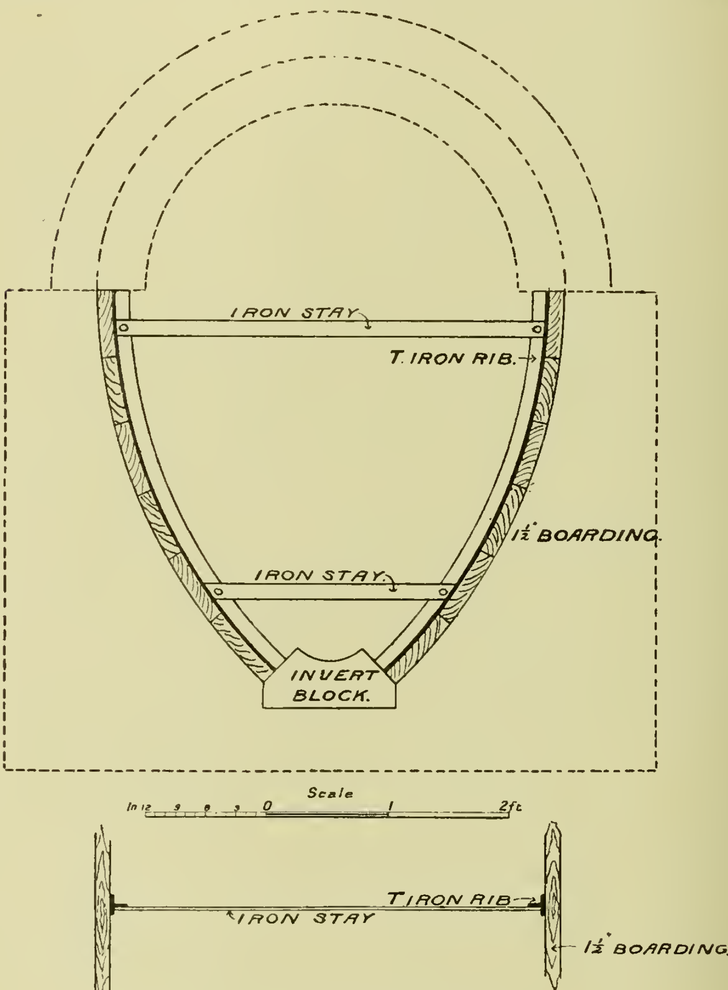


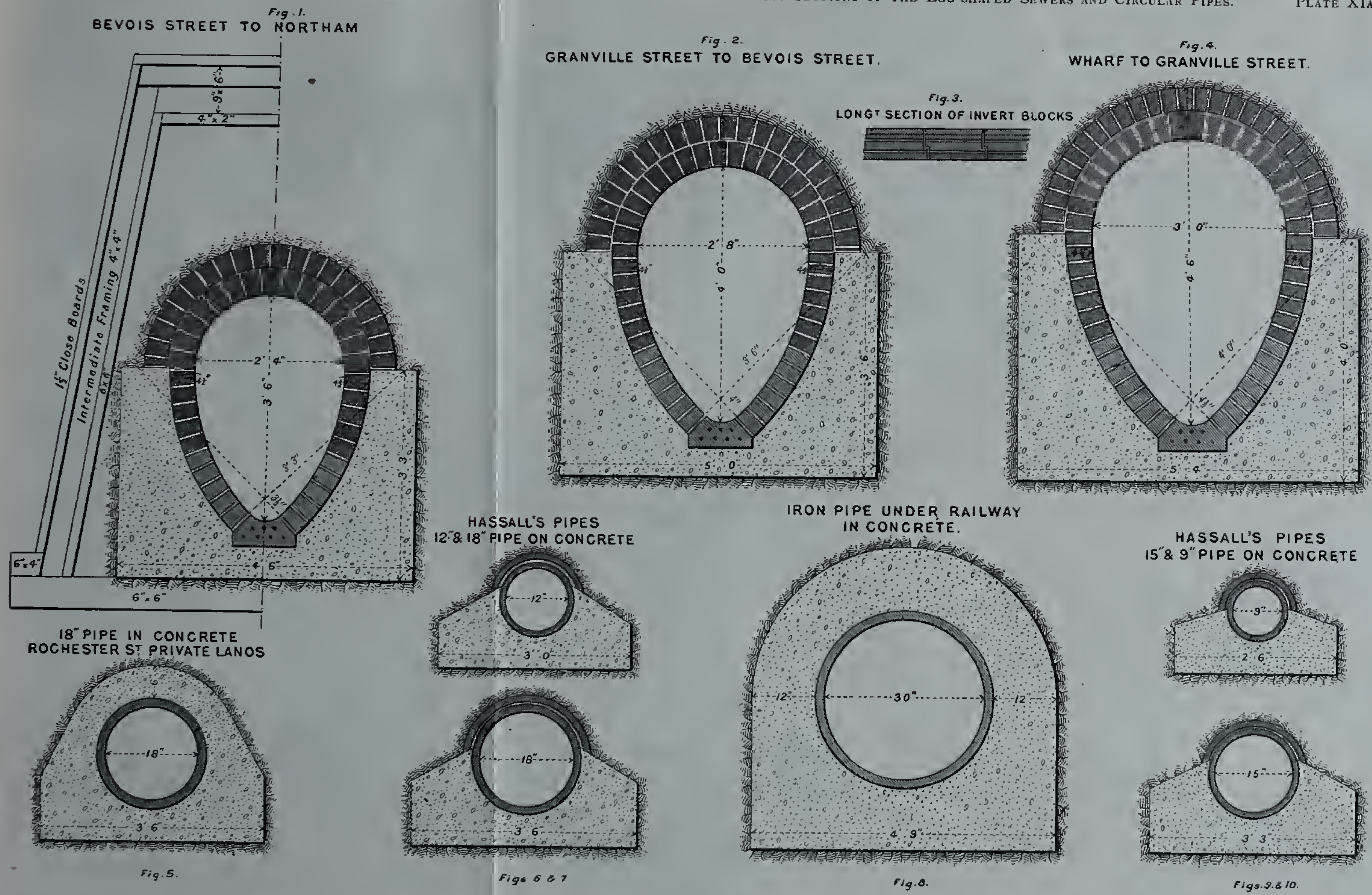
FIG. 113*b*.—Moulding Core of Invert.

drains was laid in separate shallow trenches independent of the main soil sewers.

Further information relating to these sewers is given in the description of the seweragc of Southampton, page 576.

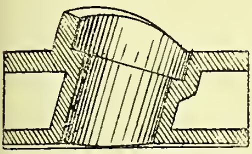
Hollow Invert Blocks, etc., ordinary pattern, of Glazed Stoneware.—Blocks of glazed stoneware, as in Fig. 111, may be used with

SEWERAGE OF THE EASTERN DISTRICT OF SOUTHAMPTON. Cross Sections of the Egg-shaped Sewers and Circular Pipes. PLATE XIA.

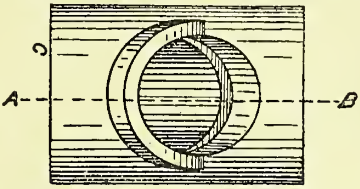


To face page 232B.

advantage for the bottom of egg-shaped sewers in brick or concrete, as they ensure an even and uniform surface where it is most required. They are generally made hollow, to prevent warping in burning. This hollow is, however, objectionable, as they have to take the weight of the



Long^l Section A.B.
FIG. 114.



Plan
FIG. 115.

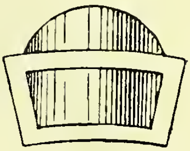


FIG. 116.

sewer, its contents, and the superincumbent earth, and, consequently, are often found split in the work. The hollow also acts sometimes as a carrier for subsoil drainage, which causes shrinkage of the foundation and settlement of the sewer, especially in sandy soils ; this hollow should, therefore, be filled in with concrete before laying. Hollow invert blocks are made with butt and lipped joints ; the latter are preferable, as less liable to settle in the work than plain butt-joints. Unless in very stable ground, the invert blocks should have a concrete foundation, as shown in Fig. 113, the subsoil drain being laid in rough cinders—*i.e.*, the fine ash riddled out, and concrete laid over it.

Similar blocks (Figs. 114—116) are also made for insertion in the side walls of sewers, to enable a proper junction to be made with drain-pipes at any angle.

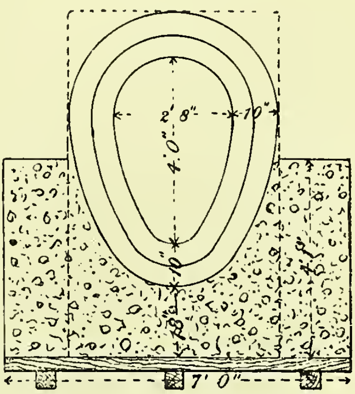


FIG. 117.—Culvert with Concrete Foundation.

Concrete.—When sewers are entirely made of concrete, the least thickness need not exceed what would be allowed in brickwork, but the concrete must be carefully made, and evenly laid.

The concrete for sewers may be composed of :—One part by measure of Portland cement to two of sand and three of broken stone, passed through a three-quarter inch sieve.

Adequate Foundation Required.—It is necessary to be careful to provide an adequate foundation for a culvert ; if the ground is at all soft, the bottom should be built with a rectangular base, as in Fig. 117.

Where the ground is of a treacherous nature, the concrete is sometimes laid on closely-wattled hurdles, or planks, resting on three longitudinal sleepers five and a half inches die square.

The dotted lines on Fig. 117 represent the size and method of construction adopted in the case of the sewers for the Thames Embankment.

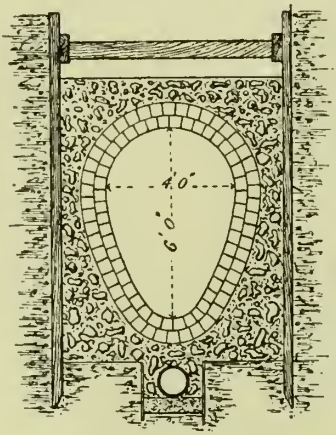


Fig. 118.—Cross Section of Tank Sewer.

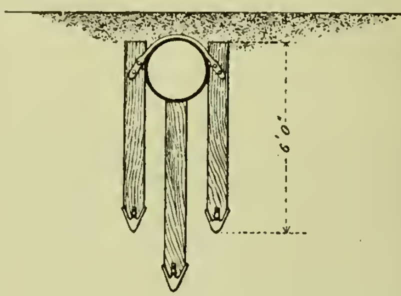


Fig. 119.—Cross Section under Sand.

They were for the most part made entirely of concrete, ten inches thick at their thinnest part, the outside being square. Some were lined with four and a half inch brick, the concrete being four and a half inches thick.

Fig. 118 shows a method of forming a culvert in sand when a spring

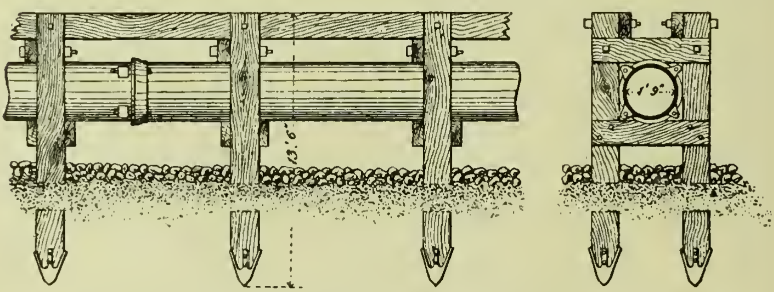


Fig. 120.—Elevation and Cross Section above Sand.

is met with, and Figs. 119 and 120 some arrangements for laying drain-pipes on bad foundations.

The former method was adopted by Mr. Baldwin Latham in carrying out the sewerage works at Redhill, and is described in his excellent work on Sanitary Engineering as follows:—

"Owing to the large amount of water present when excavating these works, it was found that, if only for a short time the operation of pumping was discontinued, the subsoil water would rise and force its way through the newly-laid concrete or brickwork of the sewer ; consequently it became necessary to make provision for admitting this water into the sewers during the progress of the works in such a way as to allow the materials a fair chance of consolidation before finally excluding the water. This was done as shown on Fig. 121, which represents a sewer constructed on an artificial plank and concrete foundation. At suitable intervals along the sewer ordinary sewer-pipes were placed upon the planks socket downwards, and afterwards filled with clean gravel, a communication being made by means of a land drain communicating with the bottom of the sewer. The water passed up through the planked floor and gravel, discharging itself free of sand into the sewer ; so that the water, having a free escape, did not injuriously affect the work, and pumping could therefore be dispensed with after the completion of the lower portion of sewer ; and, owing to the small apertures left for the purpose of admitting the spring water into the sewer, at any time that might be thought desirable after the consolidation of the work, the spring water could be effectually shut out."

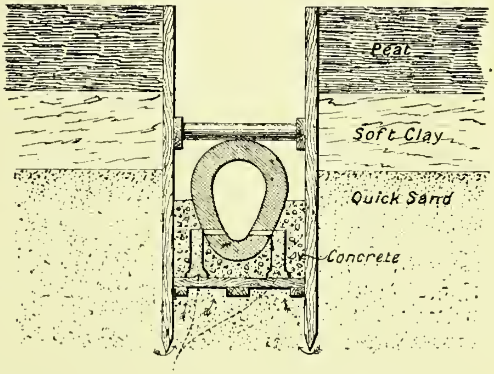


FIG. 121.—Sewer constructed on artificial plank and concrete foundation.

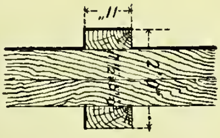


FIG. 122.

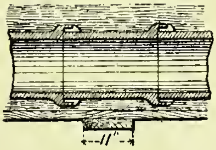


FIG. 123.

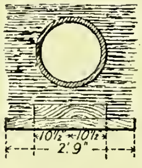


FIG. 124.

Where planks are used, the pipes should bear uniformly on them, to allow which it is necessary to lay upon the planks a sufficient depth of good material.

When stoneware drain-pipes are used in soft ground, a cement concrete bed should be formed to suit the invert, and laid to the fall, its width being twelve inches greater than the bore, and depth varying with the diameter. The following sizes are recommended as suitable, viz. :—

TABLE 68.

Internal Diameter of Pipe in Inches.	Thickness in Inches.	
	Under Pipe.	At side of Pipe.
4	3	5
6	$3\frac{1}{2}$	6
9	4	7
12	$4\frac{1}{2}$	$8\frac{1}{2}$
15	$5\frac{1}{2}$	$10\frac{1}{2}$
18	6	11

In cases where the outfall pipes are laid on a foreshore, the action of the sea is liable to uncover and also undermine them.

If the pipes are laid in sand, which is liable to shift with the tide and wind, care should be taken to prevent the lateral movement by piling, and also to afford them efficient support in a similar manner. Arrangements for carrying pipes bedded in sand, etc., are shown in Figs. 122, 123, and 124, page 235. Fig. 122 is a plan of a plank formation for sewer pipes of fifteen inches and larger diameter, Figs. 123 and 124 being

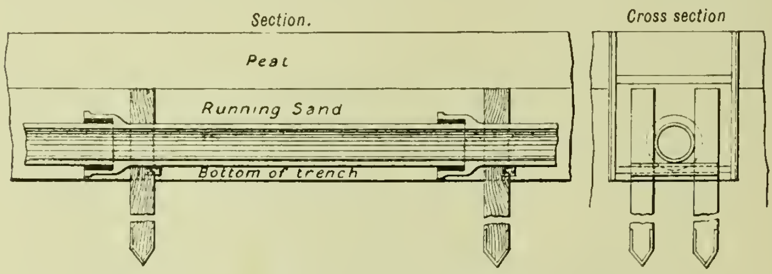


Fig. 125.—Foundation for Iron Pipe Drain in bad ground.

longitudinal and transverse sections of the work. Fig. 125 shows the foundation for iron pipe drains in bad ground.

Manholes.—In a large system of sewerage, it is usual to place manholes, or inspection pits, about 100 yards apart, or eighteen to the mile ; and, even on a small scale, inspection pits, or manholes, are necessary, with lampholes between two pits.

The manholes are intended for examining and clearing the drains. Lampholes are intended for letting a lamp down into the sewer at the upper ends, or at intermediate points where the size of the sewer is small and would interfere with the sight from one manhole to another;

if the light is shut out from view it shows the presence of some obstruction in the drain. Lampholes should not be placed at bends except in brick culverts.

It is most desirable, in order to admit of periodical inspections of the drains, to have manholes and inspection pits at all junctions and bends.

The manholes should be of simple construction, and may be made to serve the additional purpose of ventilating openings, side entrances to large sewers (Fig. 126), and flushing chambers, as occasion may require.

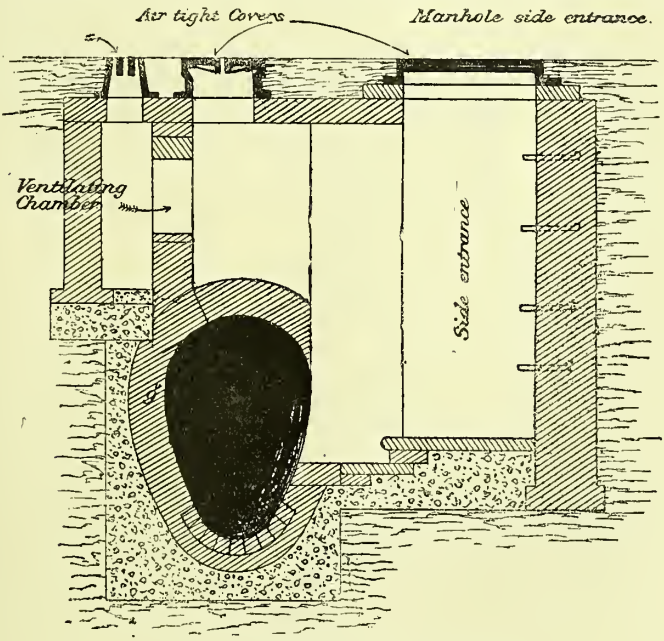


FIG. 126.—Manhole with Sluice-valve.

Plate VII., page 18, shows a manhole used in the Metropolitan Sewerage system, and fitted with a sluice-valve.

The method of effecting the junction of the pipes at the bottom of the manhole by a curved half-round channel is, however, of universal application.

The rock-concrete manholes shown in Figs. 127—129, page 238, are formed of rings made in sections, and thus manholes of any depth can be constructed cheaply and quickly. They are especially suitable for use in water-logged ground. They are absolutely water-tight; no internal cement rendering is necessary; a perfectly smooth and clean interior is preserved.

The substance of the rings is easily cut, with a sharp diamond pointed chisel, for ventilating holes or high-level side inlets.

ROCK CONCRETE MANHOLES FOR SEWERS AND HOUSE DRAINS.

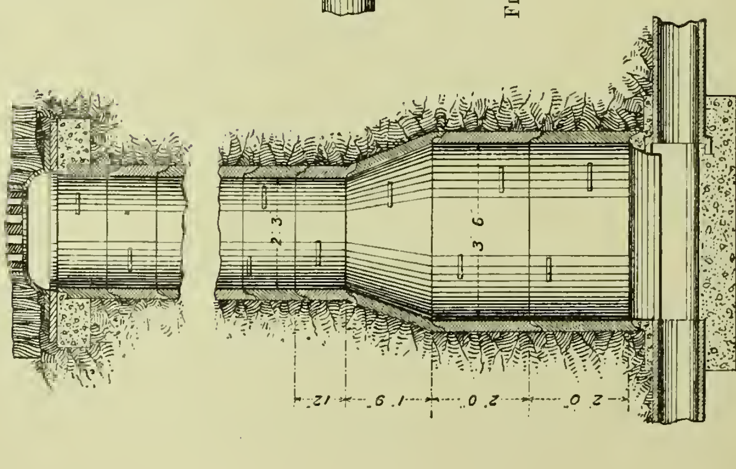


FIG. 127.—Large Size for Sewers.

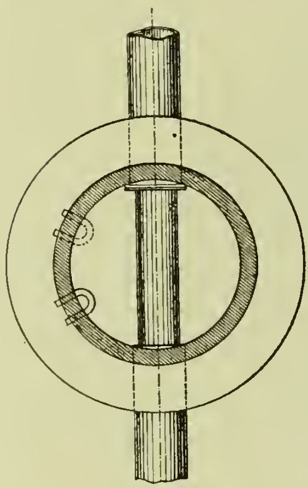
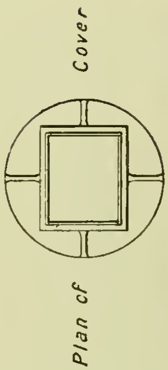


FIG. 128.—Plan of Manhole shown in previous figure.



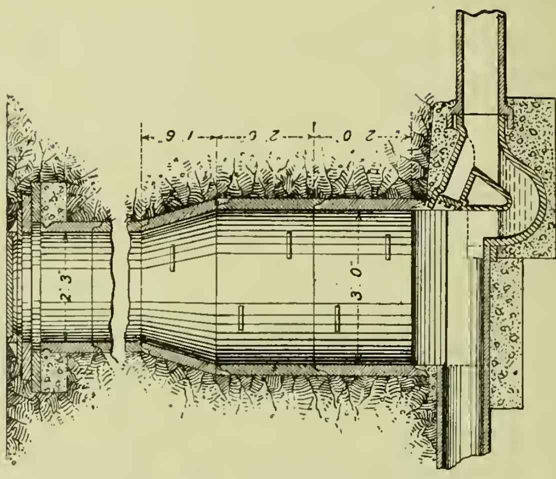
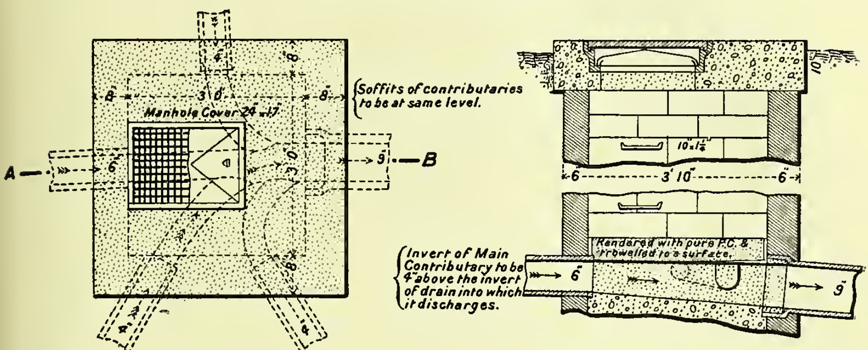


FIG. 129.—Small Size for House Drains.

This principle would appear to be equally applicable to the construction of rain-water tanks, cesspools, and wells. The top pieces may be used alone for small manholes.

Junction Pits.—It is desirable to have junction pits (Fig. 130) at all points where the branch pipes join the main channel, and also at all



Plan. Section on line AB.

FIG. 130.—Junction Pit.

bends, and if these are placed sufficiently near to each other the pipes can then be readily cleared of any obstruction.

White Enamelled Channels. — White enamelled channels (Figs. 131—133) are advocated for use in connection with junction pits, but channels may be formed with salt-glazed tiles or of pure cement finely rendered, which is easier of application.

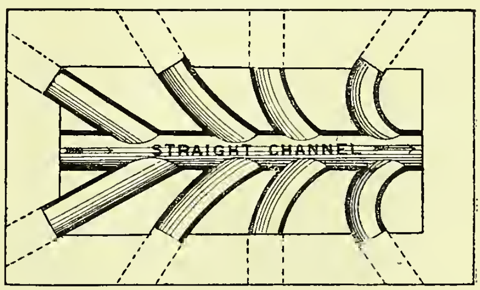


FIG. 131.

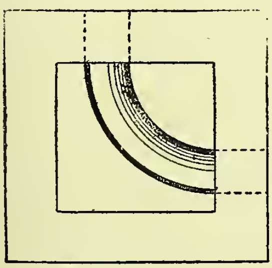


FIG. 132.

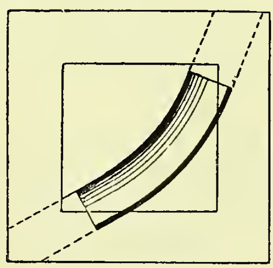


FIG. 133.

White Enamelled Channels.

Air-tight Covers.—Unless used as a ventilating shaft, the mouth of a manhole should be closed with an air-tight cover.

Jones's patent automatic seal air-tight manhole cover is shown in Fig. 134.

It is provided with two covers, the inner of which is arched, which allows the moisture from the drain to rise to the apex of the arch, where it condenses and runs down to the groove prepared for its reception, into which the cover fits, thus forming a reliable air-tight water seal. The top cover is flat with the surface of the ground, and also fits into another groove that may be filled with any suitable material, thus forming a second seal. Traffic passing over the top cover cannot possibly disturb the inner seal. The manufacturer, Mr. John Jones, claims that these covers are more simple and secure in action than any others extant.

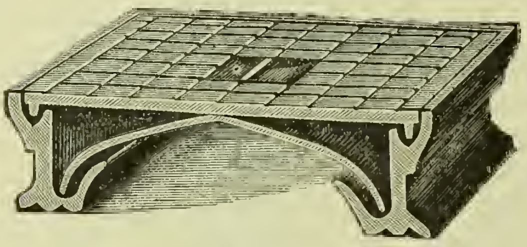


Fig. 134.—Air-tight Manhole Cover (Jones's patent).

Very good air-tight manhole covers are made by Broad & Co. and others.

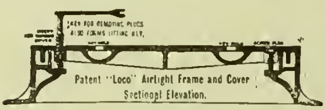


Fig. 135.—"Loco" Manhole Frame and Cover.

The "Loco" Manhole Frame and Air-tight Cover.—The frequent trouble caused by the covers of ordinary manhole frames becoming tightly fastened by the dirt, &c., which fills up the recess round the covers by the constant traffic of foot-passengers over them, has been successfully obviated by a very simple and effectual method of raising the cover by the power exerted by means of a screw, as illustrated in Fig. 135. The screw-threads in the holes of the cover are preserved by brass plugs, which are removed when the cover is required to be taken off. The key and the screw for removing and replacing the plug and raising the cover are formed of one piece of steel, which simplifies the operation. The covers are also formed with cemented surface for pavements, instead of being of cast-iron, as for ordinary manholes.

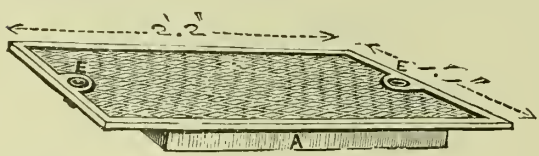


Fig. 136.—Cast-iron Manhole Cover (small size).

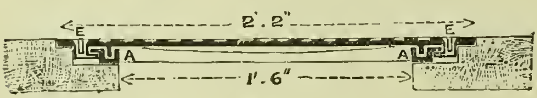


Fig. 137.—Section of Manhole shown in Fig. 136.

If desired, the covers may be so arranged as to be fastened down by the screw plugs.

Manhole Cover, Hellyer's.—A "small size" cover, as supplied by Mr. S. S. Hellyer, is shown in Figs. 138 and 139. The channel (A) is filled with a special composition, into which the tongue on the covers is bedded in order to make it air-tight. The cover is secured by a brass turn buckle (E).

The covers supplied by Messrs. Ham, Baker & Co. have a packing of asbestos to render them air-tight. There are a great variety of patterns made by Messrs. J. Stone & Co., W. H. Bodin & Co., and others.

Cast-iron Drain-pipes are used in many instances on account of the greater security they afford against any possible escape of sewer-gas. Advantage is also taken of their extra strength in crossing open spaces, where ordinary glazed pipes would be liable to be damaged by traffic or other causes. Iron pipes, if of proper weight, never break; they can be made of any size, and so might take the place of culverts. Cast-iron pipes may be used for main sewers with economy and advantage, for instance, where the course of the drain is through made or unfirm ground, or where the strata is full of water; also in narrow streets, where deep trenches have to be excavated. A cast-iron drain-pipe may be two-thirds the diameter of an earthenware pipe or a brick sewer, as the cast-iron pipe may work full and even under pressure. They have great advantages over stoneware pipes, and are becoming increasingly used, but the cost stands in the way of their general introduction; there is less labour in laying them, as they have fewer joints, being made in six, nine and twelve-feet lengths, in place of two feet; they are more accurate in form, and have less defects on the inner surface than stoneware pipes, as, with every care, the latter twist and crack slightly in the baking.

A five-inch iron pipe might sometimes, with advantage, be used in place of a six-inch glazed pipe, as it would clear itself better.

The following Table gives the weight and thickness of cast-iron pipes suitable for drains :—

TABLE 69.

Bore of Pipe.	Net Length when laid.	Thickness of Metal.	Depth of Socket.	Thickness of Socket.	Weight per Pipe.
Inches.	Feet.	Inches.	Inches.	Inches.	cwts. qrs. lbs.
4	9	$\frac{3}{8}$	3	$\frac{11}{16}$	1 1 20
6	9	$\frac{7}{16}$	$3\frac{1}{2}$	$\frac{13}{16}$	2 1 27
9	9	$\frac{9}{16}$	4	$\frac{13}{16}$	4 2 24

The following Table gives the weights of three descriptions of cast-iron socket pipes as made by the Thames Bank Iron Co. The length of pipe, including the socket in each case, is 9 feet 4 inches :—

TABLE 70.

Diameter of Pipe.	Weight per 9-feet 4-inch length.		
	Light.	Medium.	Heavy.
Inches.	cwt. qrs. lbs.	cwt. qrs. lbs.	cwt. qrs. lbs
3	0 3 17	0 3 24	1 0 4
4	1 1 18	1 1 24	1 2 4
5	1 3 18	1 3 24	2 0 4
6	2 1 18	2 1 24	2 2 4

The following tables of cast-iron pipes, both heavy and light, as manufactured by Messrs. Ham, Baker & Co., will also be useful for reference :—

TABLE 71.—HEAVY, FOR 300 FEET WORKING HEAD. TESTED TO 600 FEET

Bore.	Thickness of Metal.	Length exclusive of Socket.	Average weight per Pipe.	Bore.	Thickness of Metal.	Length exclusive of Socket.	Average weight per Pipe.
Inches.	Inches.	Feet.	cwt. qrs. lbs.	Inches.	Inches.	Feet.	cwt. qrs. lbs.
1½	5/16	6	0 1 8	10	9/16	9	5 0 16
2	3/8	6	0 2 4	12	5/8	9	6 3 13
2½	3/8	9	0 3 18	14	11/16	9	8 3 23
3	3/8	9	1 0 10	15	11/16	9	9 2 3
4	3/8	9	1 1 20	16	3/4	9	10 3 27
5	13/32	9	1 3 24	18	13/16	9	13 1 12
6	7/16	9	2 1 27	20	7/8	9	16 0 4
7	1/2	9	3 1 0	24	1	9	28 1 23
8	1/2	9	3 2 23	30	1¼	9	44 0 0
9	9/16	9	4 2 24				

TABLE 72.—LIGHT. TESTED TO 300 FEET.

Bore.	Thickness. of Metal.	Length exclusive of Socket.	Average weight per Pipe.	Price, Coated with Dr. Angus Smith's Solution.		Jointing Materials.	
				Per ton.	Per yard.	Lead.	Yarn.
Inches.	Inches.	Feet.	cwt. qrs. lbs.	£ s. d.	£ s. d.	lbs. ozs.	ozs.
1½	1/4	6	0 1 2	7 0 0	0 0 11¼	1 4	1
2	1/4	6	0 1 14	6 12 6	0 1 3	1 12	1¼
2	5/16	6	0 1 22	6 12 6	0 1 6	1 12	1¼
2½	5/16	6	0 2 0	6 10 0	0 1 7½	2 0	1½
2½	5/16	9	0 3 0	6 10 0	0 1 7½	2 0	1½
3	5/16	9	0 3 14	6 7 6	0 1 10½	2 4	2
3	11/32	9	1 0 0	6 7 6	0 2 1½	2 4	2
3½	5/16	9	1 0 14	6 5 0	0 2 4½	2 12	2½
4	5/16	9	1 1 14	6 2 6	0 2 10	3 6	2¾
5	3/8	9	1 3 14	6 0 0	0 3 9	6 0	4
6	13/32	9	2 1 14	6 0 0	0 4 9	8 0	5½
7	7/16	9	2 3 14	6 0 0	0 5 9	8 8	6¼
8½	15/32	9	3 1 14	6 2 6	0 7 0	10 0	8
9	1/2	9	3 3 14	6 7 6	0 8 2	13 14	12
10	1/2	9	4 2 14	7 0 0	0 10 10	15 0	14
12	9/16	9	6 1 0	7 0 0	0 14 7	17 3	16

Material for.—Cast-iron drain-pipes should be made with good tough grey iron from the second melting, be smooth inside, true in section, perfectly straight in the bore, with an even thickness of metal throughout, free from air-holes, sand-holes, and other defects.

They should be capable of withstanding a head of 200 feet of water. They are usually coated with some preparation to prevent corrosion.

Coating for.—Where Dr. Angus Smith's process is adopted, the pipes should be coated before leaving the foundry, as otherwise the surfaces will become oxidised and interfere with the work. The sand scale and rust have to be carefully removed before it can be applied. The composition consists of a mixture of coal tar, pitch, and a little linseed oil, heated to a temperature of 400° Fahr. The pipes are dipped into this bath vertically and allowed to remain for about ten minutes, after which they are gradually removed, so that any surplus composition may drain off. The coating should adhere firmly to the pipe and be sufficiently tough not to crack or peel off; the thickness should be uniform, and about ·01 inch.

When the Bower-Barff process is employed, the pipes have in the first place to be similarly cleaned, and subjected to a temperature of 1200° Fahr. for a period of from eight to ten hours in an atmosphere of superheated steam. The surface of the pipe becomes in this manner covered with a layer of black oxide of iron which is supposed to be totally unaffected by air or damp.

Scott-Moncrieff System.—Mr. W. D. Scott-Moncrieff, M.S.I., in a paper read by him at the R.E. Institute, Chatham, and published in the Professional Papers of the Corps of Royal Engineers, said :—"The materials used for the construction of drain-pipes are practically confined to stoneware and cast-iron. The disadvantage of the former consists chiefly in the short lengths in which they are manufactured, requiring a large number of joints, and their liability to fracture ; and conversely the advantages of cast-iron are : (a) the long lengths in which it can be manufactured ; (b) the corresponding reduction in the number of joints as compared with stoneware ; (c) its superior strength and capacity to resist fracture ; (d) the facilities afforded for making strong and reliable joints ; (e) the adaptability of the material to every variety of form.

"Until recently stoneware pipes have been used to the exclusion of all other materials, but they have this great disadvantage, in addition to those I have already mentioned, that, even when laid with the greatest skill, they are not suited to stand the test of water-pressure which is now generally applied to them. If this be the case, the comparative merits *per se* of the rival materials, earthenware and cast-iron, becomes a question for merely academic discussion, if it can be shown that the latter is capable of standing the test for a sufficient number of years to justify its adoption on the score of permanence. In other words, the suitability in other respects of stoneware becomes valueless if there is no certainty that it will pass the standard which is now universally applied to it. It appeared to me many years ago that, under the tests of water-pressure, the use of stoneware pipes, especially beneath buildings, must be definitely abandoned, and I have long ceased to employ them. The loss of money which has befallen the householder of our large towns through the use of stoneware drains is simply incalculable, and though I think it may be reasonably maintained that in many cases where a slight leakage occurs the danger to health arising from it is practically negligable, the fact remains that an intending purchaser or tenant who takes advantage of the water tests to protect himself can allege that the drains are defective if they leak at all. On this account it frequently occurs that houses in London are re-drained over and over again within a few years, each new occupier or purchaser having them re-laid, only to find that they are again inadequate to stand the water test at the end of the tenancy.

"The points to be considered in adopting cast-iron drains are as follows :—(a) The available means for preserving them ; (b) the determination of the capacity and weight of the pipes ; (c) the character of the connections best suited to the material ; (d) the nature of the joints ; (e) the comparative cost.

"With regard to the life of cast-iron for domestic drainage, the following statement may be accepted in general terms :—(1) All pipes of inclination which come in contact with ordinary sewage show no sign of interior rusting even after many years of use, owing to the greasy nature of the liquid discharged ; (2) the same remarks apply to vertical pipes washed with sewage ; (3) no ventilating pipe should be made of cast-iron, because it rusts rapidly from exposure to the gases from domestic sewage, as well as from the air of towns. From this it follows that it is safer to make all vertical soil and ventilating pipes of lead, and when lead is used for pipes of inclination they should be supported throughout their entire length, to avoid sagging.

"Having once adopted cast-iron, the facilities for perfecting the details of domestic drainage become enormously increased. In the case of stoneware appliances, they must be worked in as they come from the potteries, and it is not safe in many cases to attempt to chip them or alter their shape in any way. With cast-iron, however, it is different, because by altering a pattern for the foundry the molten metal can be poured into any shape required, and the possibilities of meeting the peculiarities of every case are unlimited. That the difference between cast-iron and stoneware is not a mere matter of theory is shown by the fact that a well-known sanitary engineering company in London are prepared to guarantee their cast-iron drainage for ten years, while they would decline to give the same guarantee for stoneware drains during a fortnight. As the whole structure is jointed in the same way as water mains, it is capable of standing a test of water a hundred times in excess of the daily pressure, which is practically *nil*. The sense of security which is obtained under such conditions is an ample return upon any small additional cost which may be incurred, though, as a matter of fact, in many cases the one material is just as cheap in first cost as the other, while in value there is no comparison.

"But cast-iron has another advantage, inasmuch as it enables us to avoid the expense which is necessary to ensure that manholes, which are frequently filled with water to test the drains, should be tight as well, and it also enables us to ensure a more rapid current for ventilation without large accumulations of contaminated air, as in the case of ordinary inspection chambers.

"Here are several specimens of cast-iron drainage details such as I have been using in my own practice for many years (Plates XII., XIII., page 248, and XIV., page 250). In what has been said, no objection is raised to the mere filling of an earthenware drain outside a dwelling with a pressure of about one pound on the square inch, in order to make sure that the joints have been properly made; but after being satisfied that the work is good, it is futile to subject the materials to a strain which, on the face of it, they are totally unfitted to stand.

"In conclusion, I should mention that in the United States of America they have long recognised the superior merits of cast-iron, and that in certain cities it is made compulsory.

"I have just described what appears to be, at least in the light of present knowledge, the best materials to be used for the pipes, and as these have above all things to be gas-tight, especially beneath buildings, it will be well to say something of the regulations which are laid down by certain local authorities with regard to them. It is unfortunate that in a great community like London these regulations are not more uniform than they are, emanating as they now do from a number of vestries. I know of cases in which architects have been obliged to change their arrangements at the last moment, and to alter their contracts, not in order to comply with more advanced requirements than they had provided for in their specifications, but in order to meet the demands of some vestry which happens to be years behindhand in the knowledge of the subject which it is their business to control."

The following Tables give weights, &c., of cast-iron pipes and fittings supplied for house drainage by the North British Plumbing Co.

TABLE 73.—APPROXIMATE WEIGHT OF SOCKET PIPES AND CONNECTIONS FOR HOUSE DRAINAGE.

Inside Diam.	Length ex-Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.
in.	ft. in.	in.	in.	c. q. lb.
1½	6 0	2¾	2¾	1 0 to 1 10
2	6 0	3	3¼	1 14 1 21 2 0
2½	6 0	3½	3¾	2 0 to 2 14
3	9 0	3½	4¼	3 14 3 21 1 0 0

Inside Diam.	Length ex Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.
in.	ft. in.	in.	in.	c. q. lb.
3½	9 0	4	4¾	1 1 0
4	9 0	4	5¼	1 1 14 1 1 21 1 2 0
4½	9 0	4	6	1 3 2
5	9 0	4½	6½	1 3 14 1 3 21 2 0 0

Inside Diam.	Length ex Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.
in.	ft. in.	in.	in.	c. q. lb.
6	9 0	4½	7½	2 1 14 2 1 21 2 2 0
7	9 0	5	8¾	2 3 14 to 3 0 0
8	9 0	5	9¾	3 1 14 to 3 3 [illegible]

Inside Diam.	Length ex Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.
in.	ft. in.	in.	in	c. q. lb.
9	9 0	5	10¾	3 3 14 to 4 2 0
10	9 0	5	11¾	4 2 0 5 0 0
12	9 0	5	13¾	5 3 0 6 2 0
12	12 0	5	13¾	8 3 0

	1½ in.	2 in.	2½ in.	3 in.	3½ in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	12 in.
	lb.	q. lb.	q. lb.	q. lb.	q. lb.	c. q. lb.	c. q. lb	c. q. lb.	c. q. lb.	c. q. lb.	c. q. lb.	c. q. lb.	c. q. lb.
Elbow	10	19	26	1 6	1 16	2 0	3 0	1 0 0	1 1 24	1 2 14	2 0 0	2 3 0	
¼ Bend	13	26	1 6	1 10	1 22	2 8	1 0 0	1 1 21	2 0 20	2 1 24	3 1 4	3 3 0	4 0 0
⅛ do.	13	24	25	1 7	...	2 0	3 26	1 1 18	1 3 22	2 1 20	3 0 0	3 1 0	3 3 0
1/16 do.	...	...	...	1 8	...	1 27	2 25	1 1 22					
Collar	11	16	23	1 26	1 2	1 8	1 14	2 5	2 24	3 14	3 20	1 0 0	1 1 2
Cap	8	8	9	15	...	23	1 1	1 8	1 24	2 10	2 22	3 12	1 1 20
Ducksfoot Bend	...	1 16	...	2 7	...	3 16							
Double Elbow, 4½ in. centres	...	...	...	1 16	...	2 10							
Do. Do. 6 in. „	...	...	...	1 17	...	2 14							
Do. Do. 9 in. „	...	...	...	1 18	...	3 0	1 0 5						
Do. Do. 12 in. „	...	...	...	1 23									
Do. Do. 13½ in. „	...	...	...	...	...	3 3							
Angle Branches	...	1 24	...	3 0	...	1 0 10	1 1 12	1 3 14					

REDUCING PIPES.

Size.	c. q. lb.	Size.	c. q. lb.	Size.	q. lb.	Size.	q. lb.	Size.	lb.
12in. to 10in.	3 0 7	8in. to 6in.	1 3 14	5in. to 4in.	3 10	2 to 1½in.	1 6	3 to 2in. Socket.	25
10 „ 9	3 0 2	7 „ 6	1 2 0	5 „ 3	3 0	6 „ 5in. 5in. Socket.	2 4		
10 „ 8	2 2 25	7 „ 5	1 1 21	4 „ 3	2 18	6 „ 4 4 „	1 25		
9 „ 8	2 1 20	6 „ 5	1 0 8	4 „ 2	2 8¾	5 „ 4 4 „	1 18		
9 „ 7	2 0 8	6 „ 4	1 0 4	3 „ 2½	2 6	4 „ 3 3 „	1 9		
8 „ 7	2 0 0	6 „ 3	1 0 0	3 „ 2	1 24	4 „ 2 2 „	1 3		

Note.—4, 5 and 6-inch pipes can also be had in 6-feet and 3-feet lengths.

TABLE 74.—DIMENSIONS OF SOCKET CONNECTIONS IN INCHES.

Connection.	1½ in.			2 in.			2½ in.			3 in.			3½ in.			4 in.			5 in.		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Elbow	10½	6½	...	13	7½	...	15	7	...	18	9	...	19½	9½	...	21	10	...	2	11	...
¼ Bend	13	13	...	17	17	...	17	17	...	17	17	...	17½	19	...	18	21	...	24	25	...
⅛ do.	18	...	...	23	...	...	23	...	...	24	...	...	...	...	...	26	...	...	42	...	...
$\frac{1}{16}$ do.	...	...	...	...	...	...	...	...	...	25	...	...	...	...	...	26½	...	...	28	...	...
Collar	8	...	...	8	...	...	9	...	...	10	...	...	9	...	...	10	...	...	10	...	...
Cap	...	...	...	4½	...	...	4¾	...	...	4½	...	...	5	...	...	5¼	...	...	5¾	...	...
Ducksfoot Bend	12½	13	...	18	18½	...	18	19	...	17	17	...	...	...	...	18	20	...	24	26	...
Double Elbow, 4½in. & 6in. centres	...	...	...	...	...	...	...	...	...	33	...	...	...	...	...	33					
Do. 9in. ,,	...	...	...	...	...	...	...	...	...	33	...	...	...	...	...	41	...	...	42		
Do. 12in. ,,	...	...	...	...	...	...	...	...	...	36											
Do. 13½in. ,,	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	42					
Reducing Pipes	...	...	...	48	...	...	...	...	...	48	...	...	...	...	...	48	...	...	48	...	...
Do. Soc. on small end	...	...	...	...	...	...	...	...	...	24	...	...	...	...	...	24	...	...	24	...	...
Angle Branches	...	...	...	42	15	...	...	...	...	42	15½	...	...	...	...	42	...	...	42	20	

Connection.	6 in.			7 in.			8 in.			9 in.			10 in.			12 in.		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Elbow	21	11	...	24	12½	...	25	11	...	24	12½							
¼ Bend	24	24	...	26	29	...	26	31	...	27	31	...	27	33	...	25	30	
⅛ do.	44	...	...	44	...	...	48	...	...	48	...	...	49	...	...	50		
$\frac{1}{16}$ do.	44																	
Collar	11	...	...	12	...	...	12	...	...	12½	...	...	13	...	...	13		
Cap	6¼	...	...	6¼	...	...	6¾	...	...	7	...	...	8	...	...	8¼		
Ducksfoot Bend	26	26																
Double Elbow, 4½in. & 6in. centres																		
Do. 9in. ,,																		
Do. 12in. ,,																		
Do. 13½in. ,,																		
Reducing Pipes	48	...	...	48	...	...	48	...	...	48	...	...	48	...	...	60		
Do. Soc. on small end	30																	
Angle Branches																		

Glass Enamelled cast-iron drain-pipes are also specially constructed for house drains, by Messrs. Shanks & Co., of a specially heavy pattern in six-feet lengths, exclusive of socket.

TABLE 75.

Sizes inside diameter	4	4½	5	6	7	ins.
Average weight of pipe	90	118	130	150	174	lbs.

Joints.—Cast-iron pipes are made both with sockets and also with flanges. Ordinary forms of socket joint are shown in Figs. 138 and 139; and of "flange" joints in Figs. 140, 141, and 142.

The sockets or "faucets" for socket pipes should be strong, with a good margin of from a quarter to five-eighths of an inch all round for caulking up, and the spigots should be provided with a half-round bead on the end to retain the caulking. The depth of the socket should be about four inches, and the lead space is slightly coned towards the face of the joint.

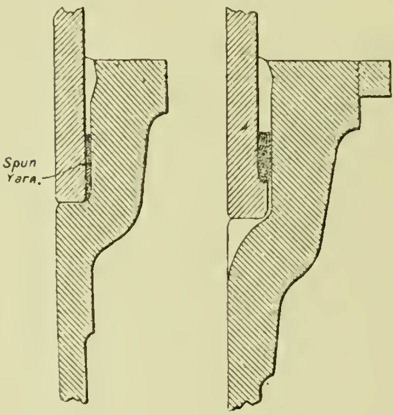


FIG. 138. FIG. 139.
Socket Joints.

Ordinary socket pipes are substituted for stoneware pipes in positions where great strength and few joints are an object, and "flange" joints where there is considerable internal pressure to be resisted which might otherwise draw the joint. The actual joint is made either by compressing an indiarubber ring, or by the close contact of the planed fillets. The latter are one and a quarter inch wide, and project a quarter of an inch.

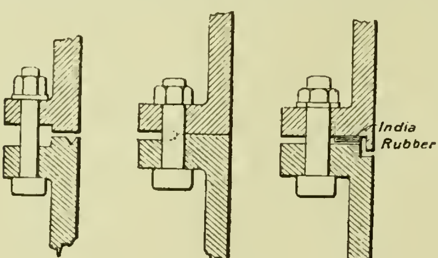
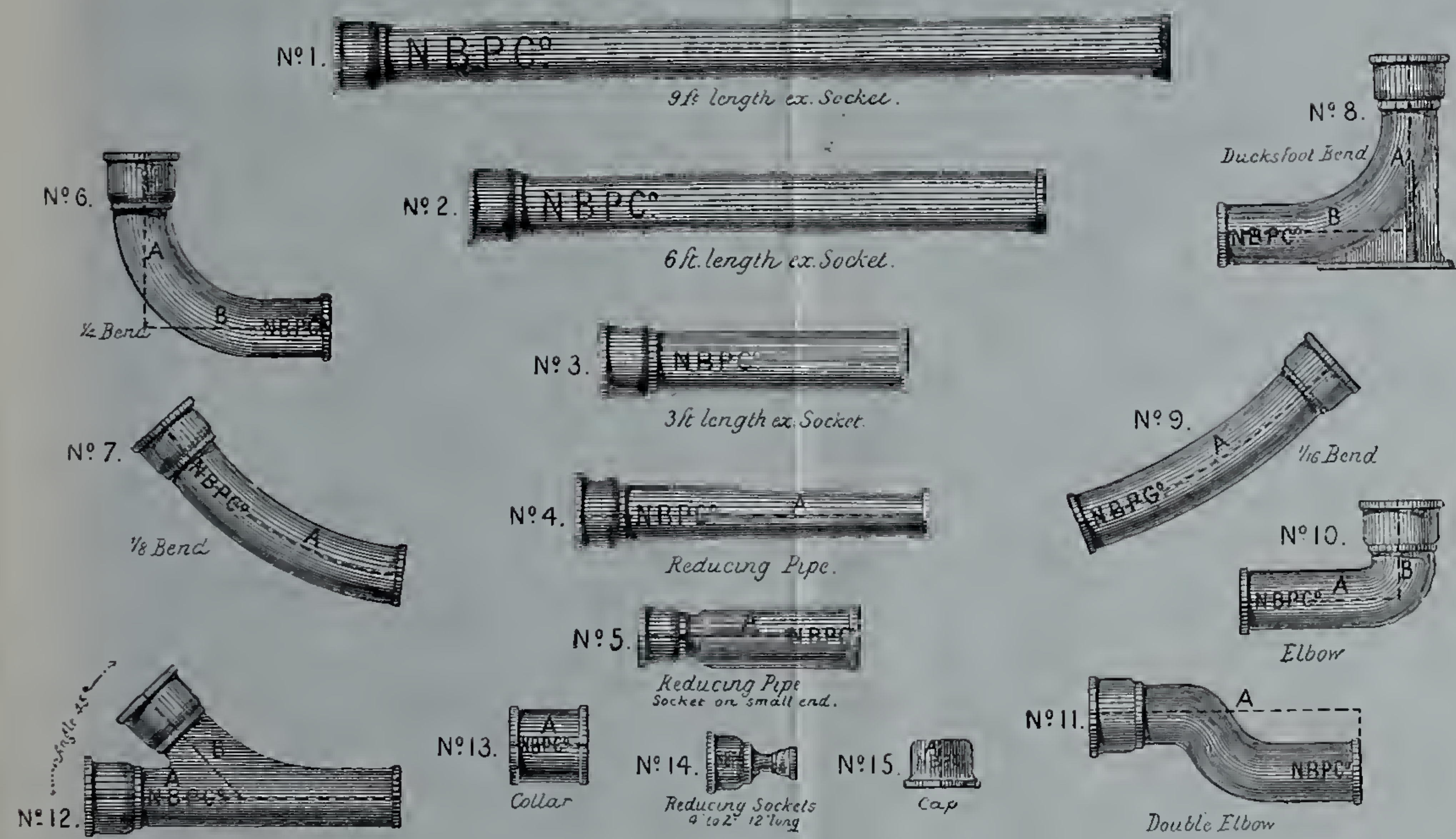


FIG. 140. FIG. 141. FIG. 142.
Flange Joints.

Turned and Bored Sockets (Figs. 143 and 144) are similar to socket joints, but the head is longer, and is turned cylindrically. The inside of the socket is also turned for about one-half its length, so that the spigot and socket fit mechanically; the remainder of the joint should be caulked with lead.

CAST-IRON DRAINAGE.

Socket Pipes and Connections for House Drainage.



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CAST-IRON DRAINAGE.

"Lever Locked" Cast-Iron Inspection Chambers.

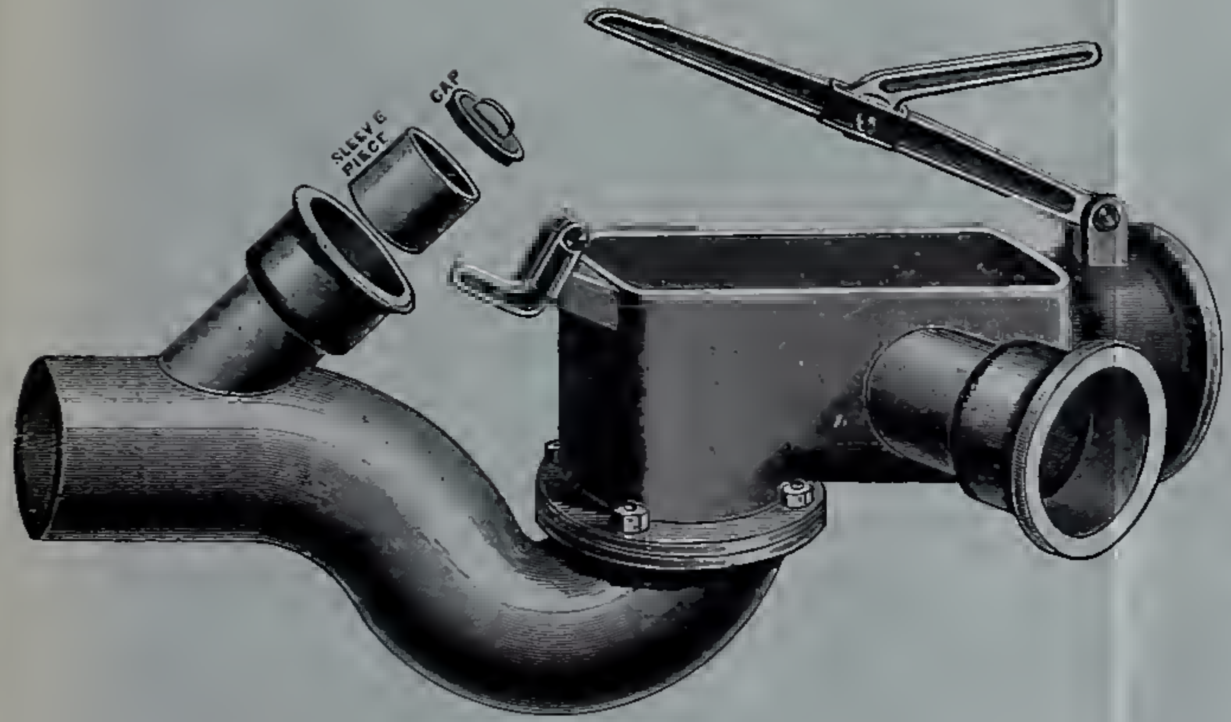


Fig. 1.—(With Trap.)

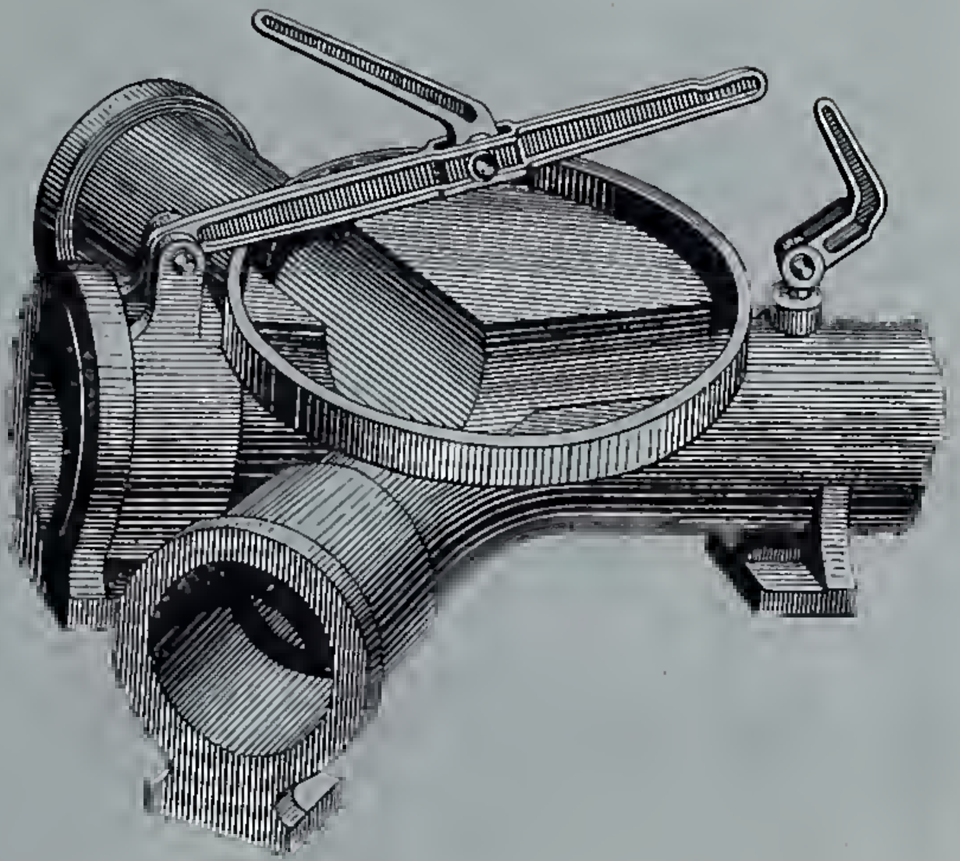


Fig. 2.

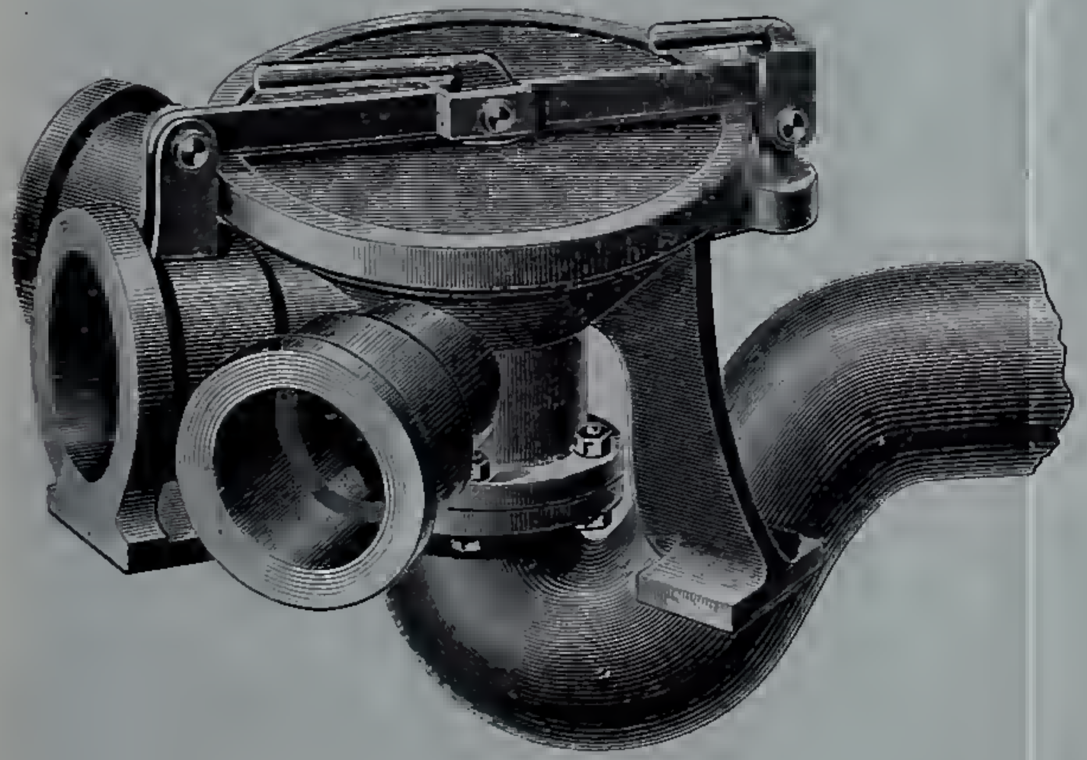


Fig. 3.—(With Trap.)

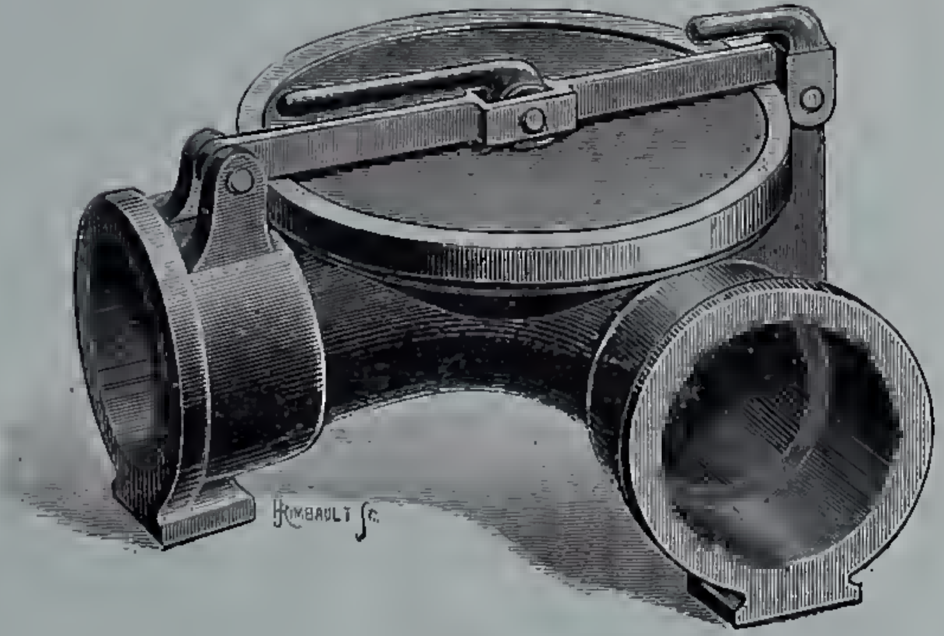


Fig. 4.—(For Bends.)

Cast-Iron Gullies.

Fig. 5.—(Surface and Intermediate Sections.)

To face page 248.

Flexible Joint.—Fig. 145 shows a joint which is easily put together, and admits of a certain amount of play, so that the pipes are not so likely to suffer from any small settlement.

Vertical Soil-pipes.—Soil-pipes, until quite recently, have been made of lead, on account of the superior security it was supposed to confer, especially as it was the fashion at the same time to carry them up inside the house. Most sanitary engineers condemn the practice of placing soil-pipes in such a position, and where met with they should be removed to the outside of the house, where, if there is any sewer gas given off in consequence of a defect in the pipe, it will not be so likely to be a danger to health.

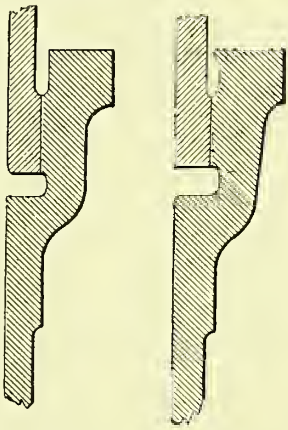


Fig. 143. Fig. 144.
Turned and Bored Sockets.

Lead pipes over two and a half inches in diameter have, up to comparatively recent years, been made of sheet lead, with a longitudinal soldered joint, and only smaller pipes were drawn without this longitudinal joint. Hydraulic drawn pipes of the larger diameter are now procurable from most makers, and should always be used in preference to seamed pipes for sanitary purposes. Soil-pipes should be pipes of uniform thickness, weighing from eight to ten pounds per foot super. Such pipes have fewer joints, but they are expensive and more liable to injury by accident than iron pipes. They should be supported in their length by pieces of lead, called ears or tacks, either double (Fig. 146) or single (Fig. 147). The method of attaching them to the pipe is seen in Fig. 148. Nails are driven through the ears into the joints of the masonry, and in some cases, for the sake of appearance, the end of the ear is turned back to hide the heads of the nails. When double ears are

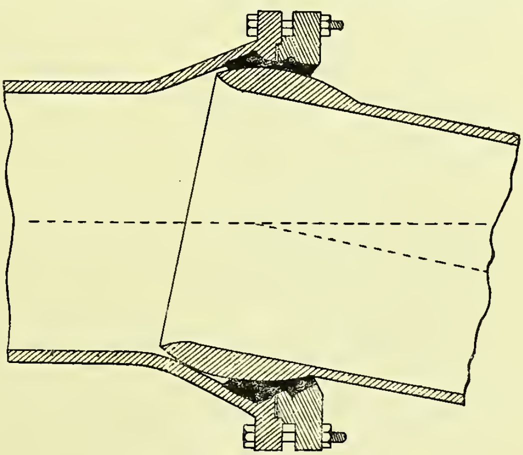
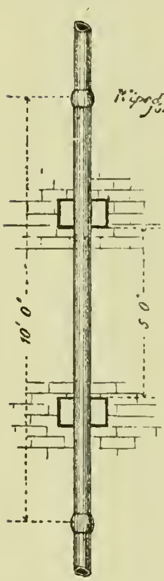


Fig. 145.—Flexible Joint.

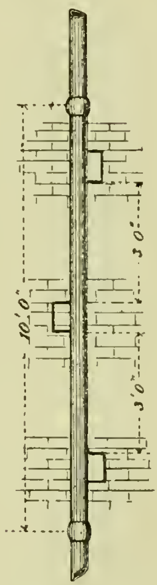
used, there should be two to every ten feet (Fig. 146) ; three or four single ears (Fig. 147) should occupy the same length. As regards the size of the ears, for pipes from two to six inches in diameter the length should be double the diameter of the pipe, and the width one and a half the diameter of the pipe, so as to allow sufficient space for nailing without injury.

Cast-iron is in some respects better than lead for soil-pipes, and is being increasingly used for this purpose outside buildings. The pipe should be at least four inches in diameter to obviate the risk of becoming



Double tack

Fig. 146.



Single tack

Fig. 147.

Lead Soil-pipes.

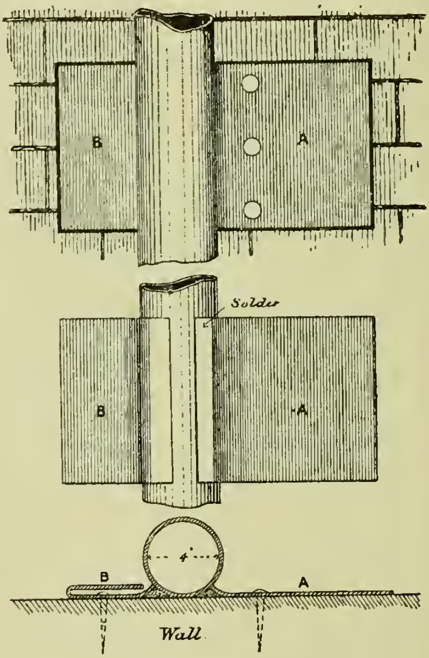


Fig. 148.—Method of attaching Ears to Soil-pipes.

choked. Ordinary rain-water down-pipes are not adapted to the purpose, as they are much too thin and, being liable to pin-holes, will neither stand the hydraulic test nor the caulking of the joints with lead, and are subject to greater corrosion than pipes of waterworks strength.

Pipes circular in section with lugs are suitable ; they should not be less than $\frac{5}{16}$ inch in thickness, and have 4-inch sockets. The lead joint should be $\frac{5}{16}$ inch thick, 2 inches deep, and take 4 and 5 lbs. of lead for 4-inch and 5-inch pipes respectively. A 6-inch pipe should have a $4\frac{1}{4}$-inch socket, with a lead joint $\frac{5}{16}$ inch thick, $2\frac{1}{4}$ inches deep, and containing about $6\frac{1}{2}$ lbs. of lead. The sockets must be sufficiently strong to stand the leading and caulking. Six-feet lengths

CAST-IRON DRAINAGE,

SHOWING COMPLETE SYSTEM OF CAST-IRON DRAINAGE AS FIXED.

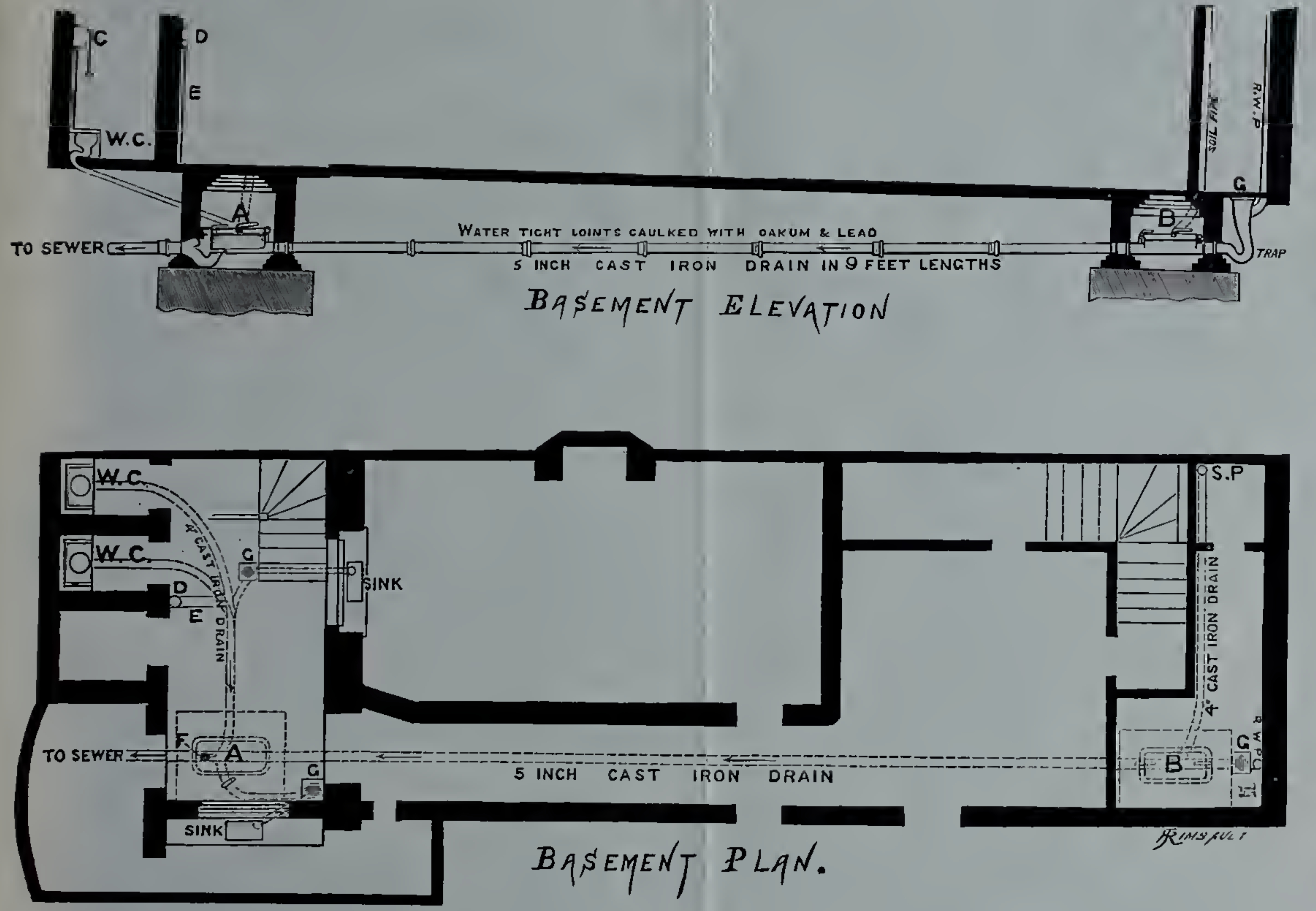


FIG. 1.

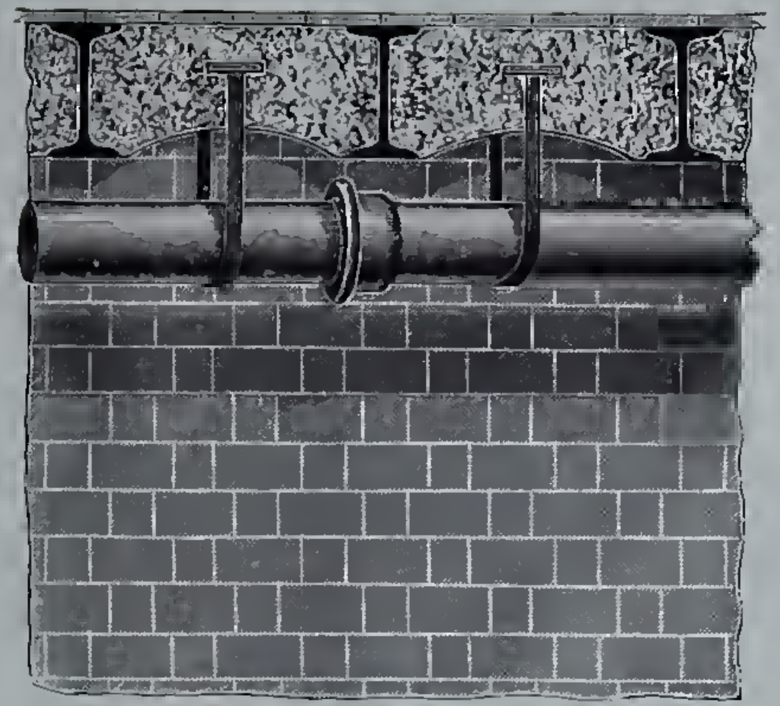


FIG. 2.

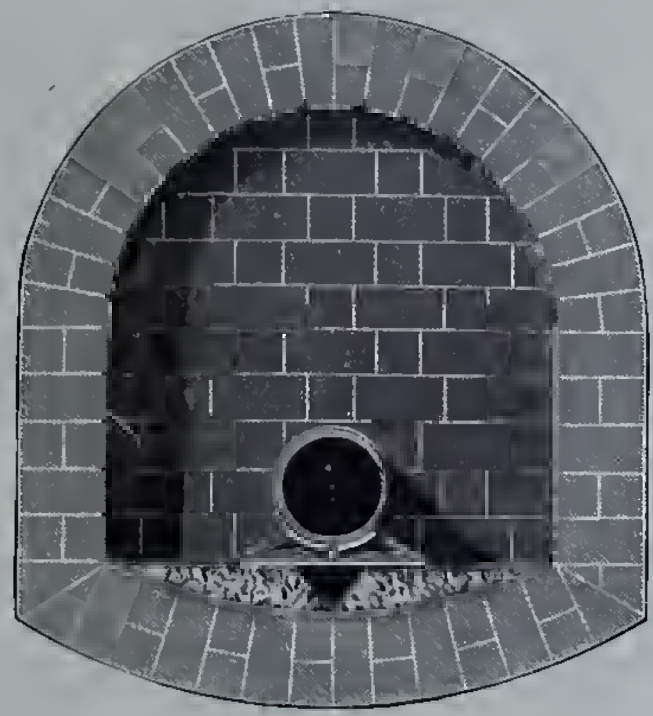


FIG. 3.

To face page 250.

of 4, 5, and 6-inch pipe would thus weigh about 85, 100, and 125 lbs. respectively.

Messrs. Shanks & Co. have introduced glass enamelled cast-iron soil-pipes, which remove the sole objection to the use of cast-iron for soil-pipes, viz., the corrosion of the interior and the consequent roughness. The enamel is impervious to the action of sewer-gas, and renders the pipe as smooth as if it were made of glass. The enamelling is done at a bright red heat, so that the enamel is hard and durable, and is of a semi-transparent, brownish colour. The process is not costly, being about the same as galvanising.

Glass enamelled cast-iron soil-pipes are made in 6-feet lengths.

TABLE 76.

No. 1. Average weight per length	2	2½	3	3½	4	4½ ins.
	24	26	34	—	44	52 lbs.
No. 2. Medium, average weight per length	2½	3	3½	4	4½	5 ins.
	28	36	40	46	54	60 lbs.

Soil-pipes, Size of.—Soil-pipes should be constructed, like ordinary drain-pipes, of as small a diameter as is consistent with efficiency ("The Plumber and Sanitary Houses," by S. S. Hellyer), if they are to be kept clean and wholesome. A 3-inch pipe is sufficient for this purpose, even where several water-closets discharge into it (Fig. 149). The question is, however, complicated by the syphonage of the traps which takes place when the water, coming down more or less as a solid plug, drives the air before it and at the same time causes a powerful suction behind it. In a many-storied house, with several water-closets branched into one main soil-pipe, it is better to increase the diameter to three and a half inches, to lessen the syphoning action. If the soil-pipe is not disconnected from the drain, a 4-inch pipe should be used to secure better ventilation. If, again, the buildings are of very great height, above six or seven stories, the size of the soil-pipe should be enlarged to, say, four and a half or even five inches, on account of the increased danger of syphoning action.

In addition to these precautions, an anti-syphoning 2-inch lead pipe, as shown in Fig. 149, is required to ventilate the traps to water-closets, and relieve the pressure on them caused by the discharge in the soil-pipe already referred to.

In buildings of great height the size of this pipe should be increased to two and a half or three inches, and it is even better to make the two pipes of the same diameter. Thus, if the soil-pipe is four inches, the anti-syphoning pipe should also be a 4-inch pipe. The ventilation pipe in continuation of the soil-pipe should be made of greater diameter than the soil-pipe, so that a 4-inch soil-pipe would require a 4½ or 5-inch ventilating pipe; and if the latter has to be carried up to some height in order to keep it clear of windows or chimneys, a 6-inch pipe would be preferable.

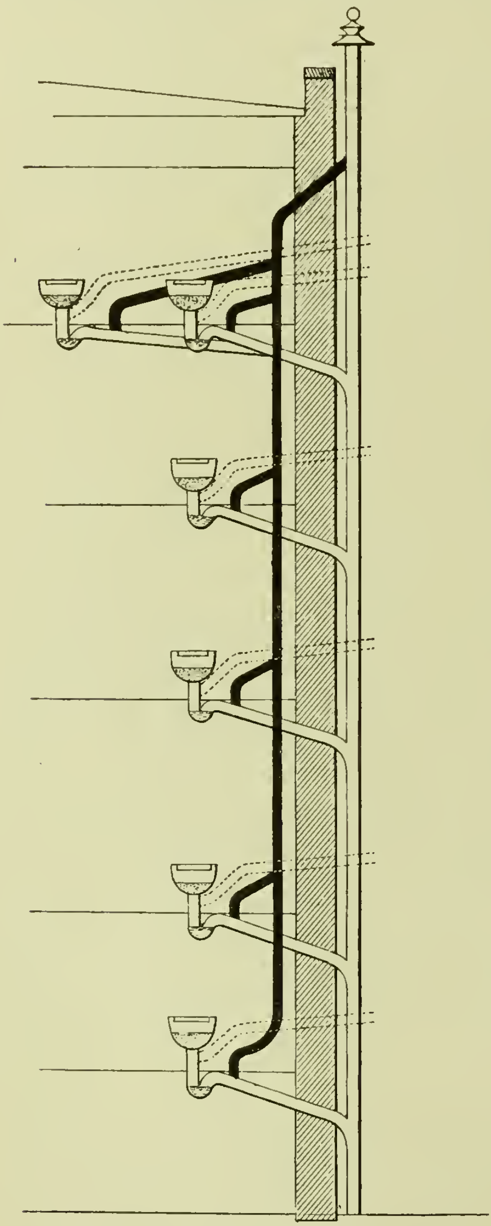


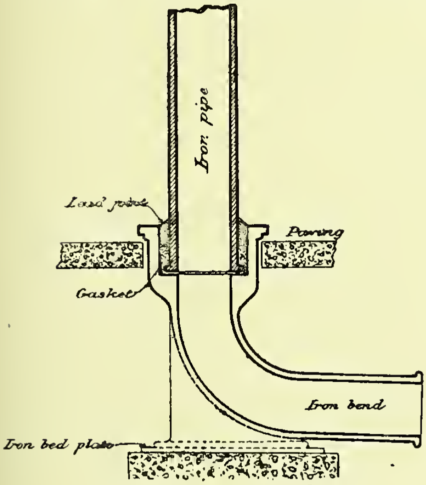
Fig. 149.—Connection of w.c.'s with Soil-pipe.

In consequence of the weight of the soil-pipe, and the damage to the joints which must ensue on any settlement at the attachments, it is advisable to support the pipe at the base by means of an iron standard at the foot of the soil-pipe. The methods recommended for making the joint between it and an iron or lead soil-pipe respectively are shown in Figs. 150 and 151. The brass ferrule in the latter case admits of the joint between the iron and lead pipe being caulked.

"Loco" Deflector Bend.—This bend (Fig. 152) forms an important feature of the system known as Draining by Deflection. For the sake of comparison, an ordinary bend is shown in Fig. 153. The arrows in both cases indicate the result of impact on the bottom of the bends, and it will be noticed that the free flow of the sewage in the ordinary bend must of necessity be obstructed, whereas by Lynde's method the force of the falling water is utilised to the best advantage, and at the same time maintains the surface of the pipes in a clean condition.

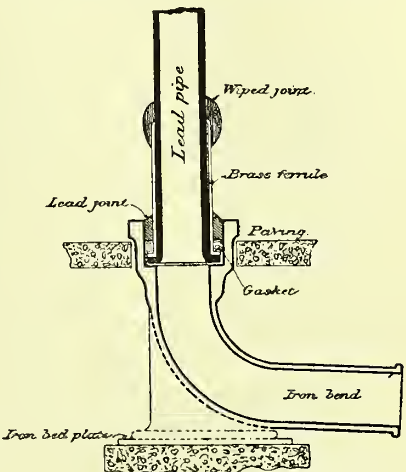
Joints in Iron Pipes (Fig. 154).—The joints should be caulked with yarn and run with lead.

Rust Joint.—Instead of a lead joint, a rust joint is sometimes made.



Connection of iron soil pipe with iron bend of drain pipe.

FIG. 150.



Connection of lead pipe with cast iron bend vertical section.

FIG. 151.

The following is the composition of the rust cement, which is also useful for other purposes.

Iron cement, or rust joint cement, is made of sal-ammoniac, sulphur, and iron turnings or borings.

If required to be quick-setting, it is made up of 1 powdered sal-ammoniac (by weight), 2 flower of sulphur, and 80 iron turnings or borings, brought to a paste with water.

FIG. 152.—The Deflector Bend.

FIG. 153.—Ordinary Bend.

If required to be slow-setting, mix up 9 sal-ammoniac, 1 flower of sulphur, and 200 iron borings or turnings.

The latter makes a better joint than the former (see Seddon's *Builders' Work*, page 214).

Traps at Foot of Soil-pipes.—A trap or syphon is necessary at the foot of a soil-pipe, to cut off the sewer-gas from the house system, unless its use can be avoided by the arrangement shown in Fig. 194, page 278, or the adoption of a disconnecting pit at some distance from the building; the objection to its use is that it checks the flow of the effluent water, and increases the difficulty of ventilating the soil-pipe.

Syphons.—Cast-iron pipes with flanges are used for this purpose; and whenever the pipes are working under pressure, all the larger sizes of pipes are made with some variety of flanged joint, as more convenient to put together than a leaded joint. A special form is shown in Figs. 155 and 156.

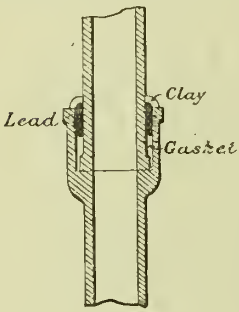


Fig. 154.—Iron Pipe-joint.

Outfalls.—These are generally made with cast-iron pipes as above.

Steel.—An outfall, 800 feet in length, was laid in the Lake of Geneva by means of a steel pipe. The pipe was boomed out from the shore as the lengths were bolted together, and thus the whole pipe to form the outfall was floated into position, advantage being taken of its buoyancy for the purpose by plugging the extremity to prevent the entrance of water. When the operation of putting the entire length together was completed, and the pipe was in its correct position over its intended resting place, the water was gradually admitted, and the pipe allowed to take its bearing. Steel was chosen as the material on account of its relative lightness and strength, so that it might be capable of standing any unavoidable stress in landing and settling on its bed.

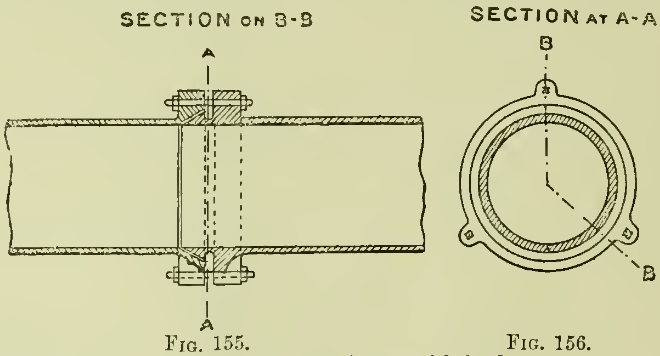


Fig. 155. Fig. 156.
Cast-iron Pipe for use with Syphons.

Lead Pipes.—Lead pipes are often used to connect w.c.'s with soil-pipes, and also as waste pipes from baths, sinks, etc., as the special form required by the particular case is more easily made locally in lead than it could be in cast or wrought iron. Cast lead junction pieces can now be obtained.

Waste Pipes.—Waste pipes from small sinks and baths are often made of light lead piping, six pounds per foot run.

Connection with Stoneware Pipe.—The connection between a lead pipe and a stoneware or iron soil-pipe should never be formed within or underneath a building, as such a joint cannot be depended on ; the pipe should, therefore, if possible, be continued through the wall, and the connection be made outside.

Variety of Joints.—Figs. 157—159 show a few of the joints which have been recommended for this purpose.

At first sight it would seem a comparatively simple matter to make an

LEAD & STONEWARE JOINT.

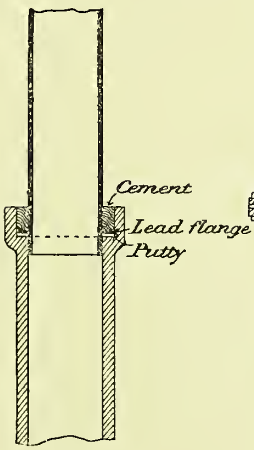


FIG. 157.

LEAD & IRON JOINT

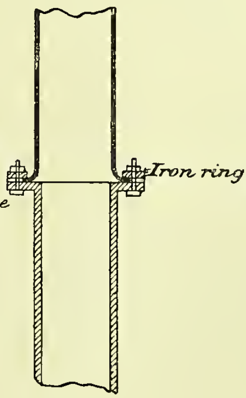


FIG. 158.

LEAD & IRON JOINT

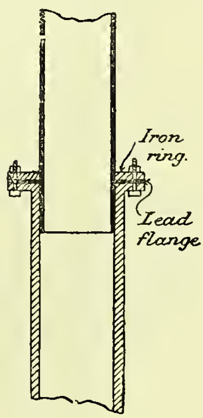


FIG. 159.

efficient joint between pipes of different materials, but the question is complicated by the variable expansion of the different substances.

Wrought-iron Piping.—Wrought-iron piping is also much used for wastes from sinks, but is neither so suitable nor so durable as lead.

Drains under Buildings.—Drains should never be laid under buildings, but where from peculiarities of site it is absolutely necessary, cast-iron pipes of water-main strength should be employed, with well-leaded joints ; the pipes also should be carefully laid on a foundation of good cement concrete. The drain should be laid in a direct line for the whole distance beneath such building, and have manholes for access to, and inspection of such pipes ; the ventilation, etc., being carefully attended to in accordance with the following chapter (page 270).

Stables: How Drained.—The drainage from stables is either collected from the stalls by underground drains or surface channels formed in the paving so as to conduct it through the wall to a gully outside the building. Many stable-owners like to have covered drains laid to each stall, and trapped, for the sake of neatness; but there is great difficulty in keeping the traps clean and in an efficient condition to prevent the inroad of sewer gas. In order to reduce the number of traps as much as possible, they are limited in some instances to one to every four stalls, in the length of longitudinal gutter. By "Ward's Improved and Registered System of Stable Drainage" (Fig. 160) the trap inside the stable is replaced by a stable pot without any trap, and the drain-pipes are led to an interceptor just outside the stable wall; the drain is provided with a ventilating pipe, and can be readily cleared from either end. This system is certainly a great improvement upon former methods. Drains under a stable are, however, objectionable for sanitary reasons, and as in the case of other buildings should always be avoided. The stable floor should be covered with an impervious material, in order to prevent pollution of the subsoil. The material used should be non-absorbent, durable, unaffected by acids, moisture, or change of temperature; it should be capable of withstanding rough usage, and of being easily cleaned. The floor should be laid with a slight fall to the rear for drainage. A great variety of materials have been employed, such as pebbles, granite pitchers (ten inches by four inches, and six inches deep), granite setts consisting of 4-inch cakes, asphalte, bricks of various kinds, such as adamantine clinkers (Fig. 161) and blue

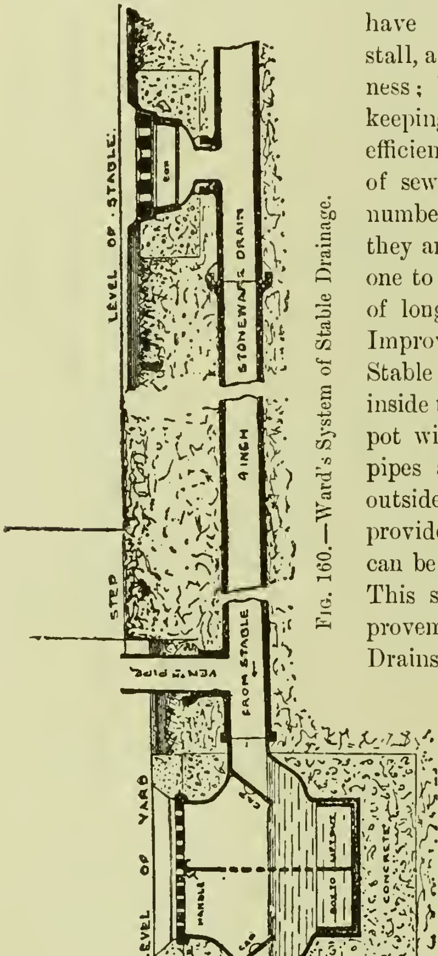


Fig. 160.—Ward's System of Stable Drainage.

Staffordshire paviours (Figs. 162 and 163). The edges are chamfered and the surfaces grooved, so as to furnish a better foothold. The cross-grooves, on the other hand, make it difficult to keep the floor clean. Wood-block paving made of creosoted timber has also been tried, but a certain amount of absorption of urine results, so that the stable never smells pure and wholesome. The objection to the use of pebbles is that they get slippery and uneven, unless bedded on concrete and jointed in cement. It is difficult even then to keep the spaces between them clean. The granite pitchers and setts have also a tendency to

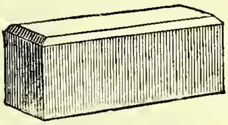


FIG. 161.

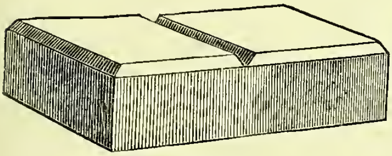


FIG. 162.

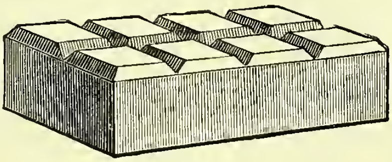


FIG. 163.

get slippery. Asphalte also shares the same objection, though, on the other hand, it is non-absorbent, and can be easily kept clean. Ordinary bricks are too absorbent. The St. Pancras Iron Work Co. has introduced a brick with one longitudinal groove only, as in Fig. 164. When a number of these bricks are laid together, a series of long parallel grooves is obtained, which requires only one direction of fall, and which is intercepted by no cross-grooves. A sweep of the broom down these grooves meets with no obstruction, and therefore clears away the dirt immediately, and liquids find their way very readily down the channels thus formed. At the end of the series of grooves is placed a gutter, which receives the dirt and drainage from them, and then conveys it to the drain-pot or to the outside of the building. In order that these grooves may conveniently be arranged diagonally with reference to the centre gutter down the stall, bricks of the pattern in Fig. 165 are utilised. This arrangement

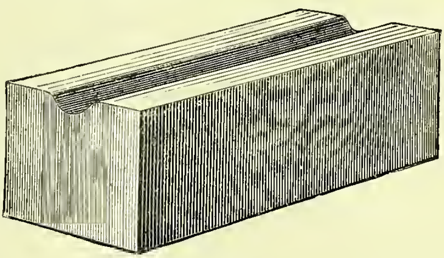


FIG. 164.

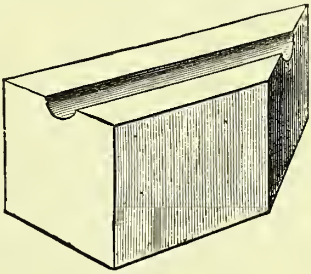


FIG. 165.

(Fig. 166) facilitates the sweeping out of the stables considerably. There are also a great many special patterns of bricks for paving stables, such as that known as "Tebutt's Patent Safety Paving." The bricks manufactured by Mr. T. Hamblett are made with flattened circular projections, projecting about three-eighths of an inch above the surface. These projections do not interfere with the drainage, and at the same time give a secure foothold. In addition to the ordinary paving, it is usual to have a shallow open gutter running longitudinally down the centre of the stall, made either of iron or of special bricks. The iron guttering is generally roughed, to check the tendency to become slippery. A specimen of wrought-iron stall guttering as supplied and fixed by the St. Pancras Iron Work Co. is shown in Fig. 167. All stable paving should be supported on six inches of good Portland cement concrete, laid on a six-inch layer of hard brick rubbish, well rammed; the joints of the paving

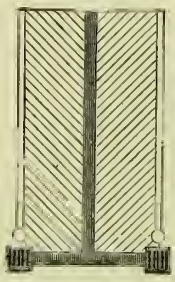


Fig. 166.

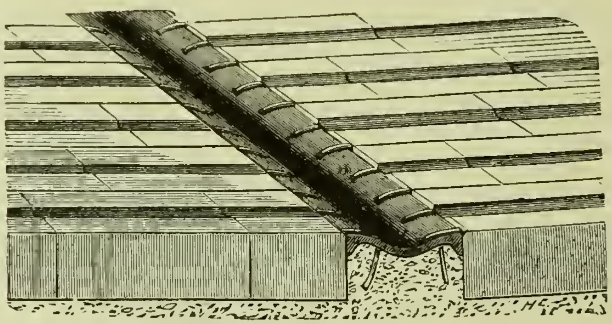


Fig. 167.—Wrought-iron Stall Guttering.

should be carefully set in cement. The best material for paving stables, according to Mr. T. E. Coleman, F.S.I., is Portland cement concrete made with the very best materials, such as granite chippings and Portland cement of the highest quality, and laid by experienced workmen supplied by competent firms. The concrete should be two and a half inches thick, and three inches where specially heavy work is anticipated; it should be floated and trowelled to proper falls as laid, and a series of grooves formed in the surface to provide a foothold for the horses, and to assist in the drainage. According to the plan adopted by Messrs. Wilkinson & Co. (Fig. 168), a central longitudinal groove is made in each stall, with two sets of parallel grooves, one on either side of it, six inches apart, in the direction of the fall at an angle of about 80°. In the case of "Ward's Patent Grooved and Channelled Granite Concrete Stable

Paving" (Fig. 169), two central grooves, with an intervening plain surface about six inches wide, is adopted. The longitudinal fall in stalls and loose-boxes, when paved with brick or granite, is one in sixty, which in a stall ten feet long amounts to a total fall of two inches between the front and back; but where the floor is made of concrete a slope of one in eighty, or one and a half inches in ten feet, is enough. The main channel along the rear of the series of stalls should have a fall of not less than one in one hundred and twenty. The grooves in the concrete floor of the stall should be saucer-shaped in section, one and a quarter inches wide, and half an inch deep at the lower end. The main channels along the line of stalls should be similarly shaped, six and a half inches wide, and one and a half inches deep, in order to allow for the general longitudinal fall of the stable floor, and at the same time to effect a proper junction of the central stall channel with the longitudinal channels. The slope of the stalls inwards towards the stall channel is one in thirty-four on one side, and one in eighty on the other. If, however, the main channel is arranged with a self-contained fall, the fall inwards for both sides of the stall towards the centre would be one in eighty. If a large open channel is considered objectionable, it may be covered with a perforated cast or wrought iron grating resting in a splayed rebate in the gutter, with the surface half an inch below the general surface of the floor, so that the stall drainage may discharge over it. There are a great variety of special cast-iron stable gutters designed to do away with all underground drainage in the stable, and at the same time to cover up the open channel which interferes with a horse's foothold. "Cottam & Willmore's Sanitary Taper Gutter, Claremont," is shown in section in Fig. 170. It is of special heavy manufacture, has a fall in itself, the top being level with the floor, and is specially made for each stable. The gutter is all fitted together, so that there is a continuous fall from the upper end to the

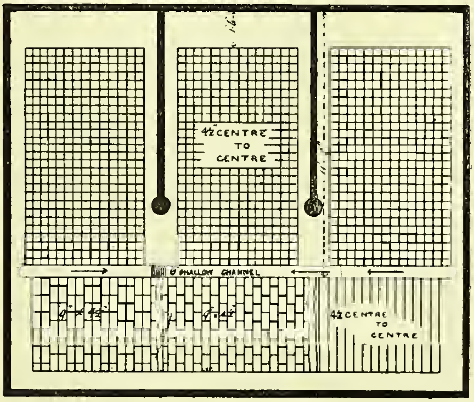


Fig. 168.—Plan of Stable, with Concrete Grooving.

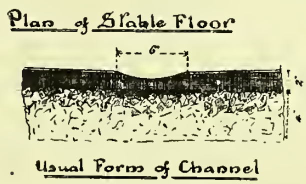


Fig. 168 A.

gully. Stables for army purposes should be drained by surface channels only, carried beyond the building to a distance of about twelve feet, and led into a suitable gully as shown in Fig. 169. Surface channels for this purpose should be formed of a hard, impervious material, in long lengths, with shallow cross section. Concrete channels, faced with pure cement, do very well.

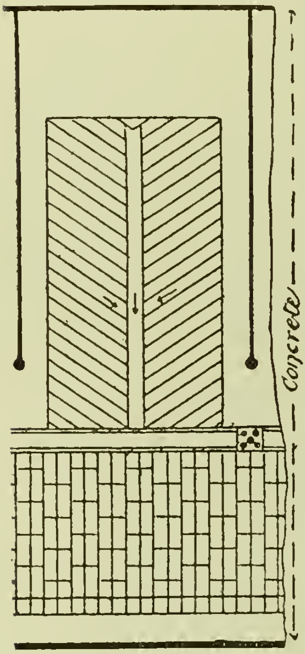


Fig. 169.—Stable with Grooved and Channelled Concrete Paving.

A long outside surface channel is sometimes considered unsightly, and then the trapped gully must be placed close to the stable wall, the drainage being simply led through the wall on to it, or conducted to it by means of an iron shoe with a hinged grating on the inside, and a sensitive flap valve at the other. The coarser solids are retained by the grating, and a further separation is effected by the bucket in the gully. The drain should have a fall sufficient to give a velocity of three feet per second when flowing quarter-inch full. Stable drainage should be kept quite distinct from the house drainage system, and be carried through a separate disconnecting-pit direct to the sewer. If a separate drain cannot be arranged, then the house drainage should be disconnected from it by a disconnecting-pit.

Fig. 170.

The stable drain should be ventilated in the manner described in Chapter VII.

Laundries, Drainage of.—No gullies or drains should be allowed inside the building, but arrangements should be made for the waste water to flow in channels through the outside walls into channel gullies, such as Mooney's Patent, and others.

CHAPTER VII.

VENTILATION.

Sewers.—One of the most important subjects which we have now to consider is the sewer-gas generated in the foul-water drains. Sewer-gas proper is described as a "fœtid organic vapour," and has for its companions in a sewer sulphuretted hydrogen, a most poisonous as well as unpleasant-smelling gas; carburetted hydrogen, due very often to leaky gas-mains or services, or to decomposing vegetable matters; carbonic acid gas, or carbonic anhydride (choke damp); and some ammoniacal compounds. The actual component parts vary considerably according to circumstances.

Decomposing Sewage Dangerous.—Sewage which has begun to decompose is more dangerous than when fresh; it should, therefore, as already stated, never be more than twenty-four hours in finding its way to the outfall; there is even then an accumulation of slime on the inner periphery of the sewers, owing to the rise and fall of the sewage line, which is constantly giving off gases, the result of decomposition.

A quick velocity of discharge, and ample flushing arrangements, are, therefore, very desirable.

There is a probability that, in addition to the above-mentioned gases, the foul air from a sewer contains some very poisonous compounds as well as organic matters floating about in it as solids, and that it is excessively injurious, and even dangerous, to inhale it. These gases and germs should, therefore, be caught and destroyed, or rendered innocuous, and thus be prevented from contaminating and poisoning the air we breathe.

According to the report made by Dr. Alessi, in the *Annals of the University of Rome* for the year 1894, on the results of experiments on the influence of sewer-gas, he found that from 75 to 100 per cent. of the animals exposed to the putrid gases from sewers died after inoculation with small doses of typhoid cultures of slight virulence, and that of all the animals not exposed only 7 per cent. succumbed after the process. Rodents and the lower animals have naturally an immunity from typhoid infection, but the animals experimented on acquired the predisposition from the action of the sewage gases; this predisposition is more easily acquired during the first two weeks' exposure than after that time, which explains "to a certain extent how some individuals, who habitually breathe air from sewers, or in whatever way corrupted, end by becoming habituated to it, and are no longer attacked by intestinal infections." "This predisposition is due to the combination of gases given out by putrid fermentations, and not to any one separately."

The inference is that sewer-gas has the power of predisposing the human constitution to attacks of typhoid and possibly other diseases, so that if the typhoid or other bacillus is then introduced into the system, it finds a favourable soil for committing its ravages. As to the extent that pathogenic germs may be carried by sewer-air, the experiments of Mr. J. Parry Laws, F.I.C., and Dr. F. W. Andrews, in 1895, tend to show that "there is no relationship between the organisms of sewer-air and sewage;" on the contrary, "the very organisms which are most abundant in sewage are precisely those which are absent from sewer-air." In addition to this, "sewer-air has no power of taking up bacteria from the sewage with which it is in contact, though it has been shown by previous experimenters, that if the splashing (in the sewer) is sufficiently violent to produce a very fine state of division of the sewage, organisms will be carried some distance, even fifty to sixty yards." They found by experiment that in ordinary sewage typhoid organisms do not tend to survive, and "their death is probably only a matter of a few days, or at most one or two weeks. But this degree of resistance may, nevertheless, be sufficient to allow of their being carried in sewage to remote distances, and of their being able to produce disastrous results should they gain access to any water supply." But although in the general sewers the probability is that the longer they remain, and the further the typhoid organisms travel, the less their chance of survival, yet, "in the drain from the typhoid block of a fever hospital, when the stools have not been disinfected for two days, a bacillus can be found which, as far as demonstration can go, is identical with that believed to be the actual cause of typhoid fever." The tendency of these reports is to show that, although in *sewers* an environment destructive of typhoid organisms exists, and that they are not taken up by sewer-air, yet they are found in specifically infected *drains*, and splashing has the effect of enabling them to be carried for considerable distances in the air.

Dr. Louis Parkes, M.D., D.P.H., states (*Journal of the Sanitary Institute*, April, 1895) that "it is clearly impossible that Mr. Laws' experiments could take account of all the varied conditions to which sewage may be subject in sewers. We know that at times steam, and large quantities of waste water at a high temperature, may be injected into sewers from manufactories. Various chemical waste products also, acid or alkaline, occasionally find their way into sewers, and may then set up chemical decomposition in the sewage, and tributary sewers frequently discharge their contents into main sewers so as to cause much splashing and agitation of the sewage. The local effects produced by these various conditions—and by others which will suggest themselves to the minds of those familiar with sewers—must be investigated at length before it is possible to assert that at no times, and on no occasions, are micro-organisms characteristic of sewage to be found in the air of sewers.

"Granting, however, for the moment, that such an assertion is correct, even then it by no means follows that sewer-air is innocuous and powerless to affect human beings injuriously. Mr. Laws himself recognises this when he writes: 'It is impossible to ignore the evidence, though it be only circumstantial, that sewer-air in some instances has had some causal relation to zymotic disease. . . . It is quite conceivable, though at present no evidence is forthcoming, that the danger of sewer-air causing disease is an indirect one; it may contain some highly poisonous chemical substance, possibly of an alkaloid nature, which, though present in but minute quantities, may nevertheless produce, in conjunction with the large excess of carbonic acid, a profound effect upon the general vitality.'

"Bacteriological science is still in its infancy, and does not at present permit of any dogmatic assertion that the microbes found in sewage are pathogenic organisms, capable of producing disease in man. According to Dr. Klein, 'the *Bacillus typhosus* is now admitted to be almost constantly present in the alimentary canal, in the mesenteric glands, and in the spleen of cases of typhoid fever, and is passed in large numbers from the body of the patient with the fæces. The organism is therefore constantly associated with the disease, but this constant association does not logically prove that the microbe is an indispensable antecedent (cause) of the disease, or even an antecedent (one of several causes in conjunction) of the disease, or, indeed, that it is anything more than a *consequence* of the disease. The chain of experimental proof necessary to completely establish the causal relationship of the organism so constantly associated with the disease is, indeed, wanting.' The absence of the *Bacillus typhosus* from sewer-air does not, therefore, prove that sewer-air does not disseminate the disease, and it would 'be wiser,' according to Dr. Parkes, 'to assign to the evidence, carefully and toilfully collected by numerous epidemiological workers, at least an equal value to the half-revealed truths experimentally arrived at in the bacteriologist's laboratory.'

"Epidemiologists and medical men generally recognise that small-pox, diphtheria, typhus, scarlet-fever, and measles are conveyed by the passage of contagion through the air from the sick to the healthy. If the air of the sick-room occupied by a sufferer from any one of these diseases was pronounced, on bacteriological evidence, to be free from the specific microbe of the disease, such a statement would not alter in the slightest the previously held opinion that the air of the room was capable of propagating infection. Surely it is best to adopt the same attitude of mind with regard to the vexed question of the specific properties of sewer-air—at any rate until bacteriological opinions opposed to such a view rest upon a somewhat surer basis. The bacillary theory of the origin of infectious disease is not yet in a position to command universal support, when opposed *in toto* to the teachings founded upon the laboriously acquired facts of epidemiological investigation."

Sir George (then Dr.) Buchanan, in his *Report on an Epidemic of Enteric Fever in Croydon in* 1875 (Appendix to Report, M.O.P.C. and L.G.B., No. vii.), wrote :—"Where sewers are small and ill ventilated, they constitute means for the rapid distribution of fever infection ; and places having such sewers may not only show fever rates maintained as high as before the sewers were made, but they may show as smart outbursts of fever as are witnessed where conveyance through water or milk is in question. Croydon itself, after it had made its sewers, and before it attempted to ventilate them, had this experience. So in other instances that have come under my personal knowledge, fever has maintained itself after pipe sewers, ill ventilated, had been laid, as in Rugby, in Carlisle, in Chelmsford, in Penzance, in Worthing ; in the last two places breaking out in severe, sudden, and diffused epidemics, without there being any question of other distribution than by sewers." With regard to the epidemic of enteric fever at Worthing in 1865, Buchanan wrote (9th Report, M.O.P.C.) that the absence of any provision for sewer ventilation, and the fact that sewer-gases had been forced up into houses through the traps of sinks and water-closets, was the cause of the outbreak, of which a positive demonstration is afforded when it is added, "that the fever almost exclusively attacked well-to-do houses on the higher levels, where the water-closets were inside the houses, and almost entirely spared the houses, mostly of a much poorer sort, situated on lower levels, where the closet was put outside the house. It was not so in the times of cesspools ; then these low-lying poor houses were far more attacked with fever than the others. Moreover, the fever subsided, as soon as openings were made into the sewers, from certain houses, where it before maintained itself for months."

According to Dr. Parkes, an outbreak of enteric fever was traced at Melton Mowbray by Dr. Blaxall (Report, M.O.L.G.B., 1881) to the occurrence of floods which backed up the sewage, specifically infected by typhoid evacuations, in the flat sewers. The air of the sewers entered the houses of the town through untrapped drain inlets and dry water-closet traps. Outbreaks of enteric fever at Sherborne in 1873 (Report, M.O.P.C. and L.G.B., No. ii., 1874) and in 1882 (Report, M.O.L.G.B., 1882) were traced by Dr. Blaxall to contamination of the water in water mains by sewer-air, there being direct communication between the water mains and the water-closets of houses. A similar state of things caused an outbreak of enteric fever at Caius College, Cambridge, 1874, investigated by Dr. Buchanan (Report, M.O.P.C. and L.G.B., No. ii., 1874); and there was an epidemic at York in 1884, also traced by Dr. Airy for the Local Government Board to the exhalations from unventilated sewers.

According to Mr. H. Alfred Roechling, C.E., 31·25 per cent. of the typhoid-infected houses in Leicester in 1893, when the smoke test was applied, were found to have defective drainage, and 45·8 per cent. in 1894. Similarly in Bristol, between the five years 1890 to 1894 inclusive, 29·38 per cent. of the houses in which there were typhoid fever cases, drainage defects were found; also in Hornsey, between the 10th August and the 30th December, 1893, nine of the typhoid-infected houses, and again, nineteen in 1894, had drainage defects revealed by the smoke test. Dr. J. Spottiswoode Cameron, in the *Journal of the Sanitary Institute* for 1897, states that at Leeds the drains of 1,121 houses where typhoid or diphtheritic disease was supposed to be present, 30·51 per cent. were tested and found to be defective.

Ventilation and Traps.—Attempts are generally made to control this dangerous product by means of ventilation, so as to admit fresh air to the sewers, and, by oxidising the sewage, to check the tendency to the formation of injurious gases. To effect this, a continuous current of air should be constantly passing through the drains from end to end, preventing the stagnation of the air in any part. The direction of the flow of the air in the sewers must be controlled by proper traps, so as to prevent its passage where it might prove injurious.

Some engineers are of opinion that the foul air invariably finds its way to the upper portions of a sewage system; but this is not always the case, for with quick velocities of discharge the gases are carried by friction in the direction of the flow of sewage.

Duty of Local Authority to Ventilate.—The necessity of dealing in some way with the noxious vapours given off from sewage, and so preventing it from finding its way into dwelling-houses, has led to its being made the duty of every local authority to cause their sewers to be ventilated, so as not to be a nuisance and a danger to health.

Points to be observed in Sewer Ventilation :—

1. The system adopted should be as simple as possible, and independent of mechanical aid.

2. Efficient expulsion of sewer-gas and the admission of fresh air at all times to every part of the system.

3. All gases thus expelled from the sewer to be diluted with fresh air, so as either to be rendered harmless, or they should be arrested and destroyed.

4. Natural ventilation must not be impeded by the system adopted.

5. The cost of construction and maintenance must be kept within moderate limits.

It is evident that the configuration of the ground on which a town is situated must affect the disposal of the sewer-gas in the sewerage system adopted.

The position of the outfall, relatively to its exposure to the prevailing winds, materially influences the direction of the flow of sewer-gas in a sewer. Under such circumstances it may be necessary to control the current of air entering the sewer by means of a hinged flap, so as to prevent undue pressure at any point.

The fluctuation of the flow level in a sewer is also an important factor, as it tends to convert inlets for fresh air into outlets for foul air, and *vice versâ*. An increase of the flow level compresses the air in the sewer, and unless means are provided for its escape, it would augment the pressure in the sewer to such an extent as to force the traps intended to exclude it.

The pressure of gas in sewers is ordinarily relieved by shafts constructed along the lines of sewers, some of which are also intended for the admission of fresh air.

These ventilators are generally placed at intervals of about 100 yards, and should never be at a greater distance apart than 200 yards, being placed somewhat closer together at the lower levels, and the intervals increased at the higher parts of the town.

Sewers with steep gradients require more care bestowed on the means for their ventilation than those in flat districts, so as to prevent dangerous accumulation of sewer-gases in the higher and lower portions of the system, and thus it is necessary to ensure the discharge and dilution of this gas as fast as it is generated.

The usual system is to break the line of sewer into short lengths between manholes, with a step, or ramp, and flap at each manhole (Plate II., page 12), so that the gas formed in each length of sewer is allowed to escape by the outlets for each section, instead of travelling the whole length of the sewer.

The steps are usually curved and of moderate depth, so that the fall

Detail of Air Inlet in Footpath.

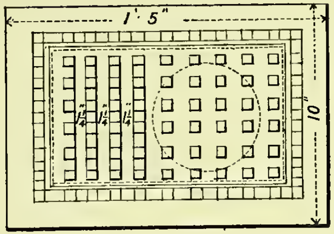


Fig. 171.—Plan.

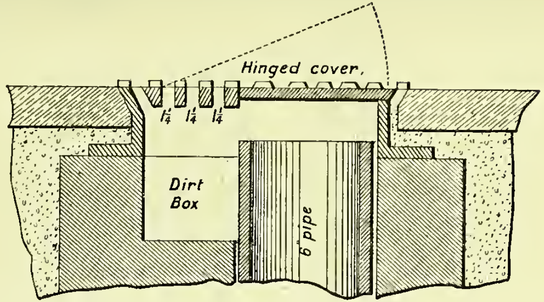


Fig. 172.—Section.

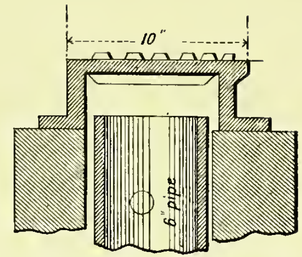


Fig. 173.—Cross Section.

Detail of Air Inlet in Kerb.

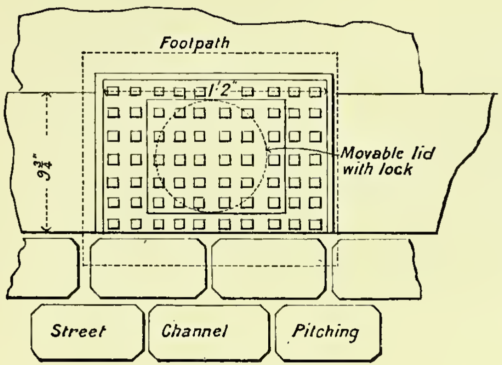


Fig. 174.—Plan.

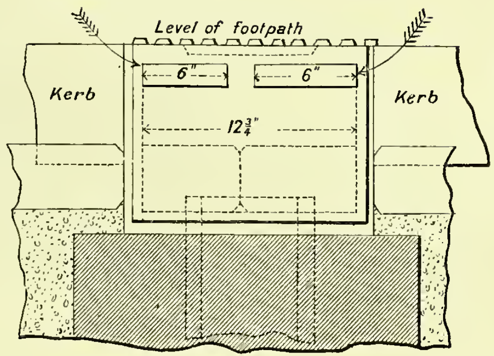


Fig. 175.—Elevation.

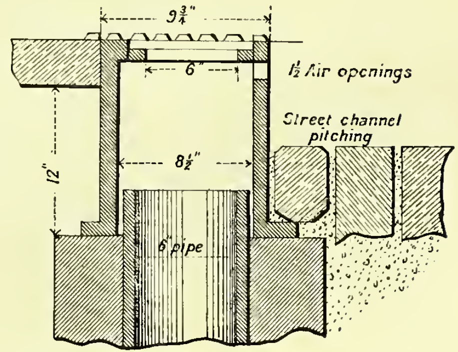
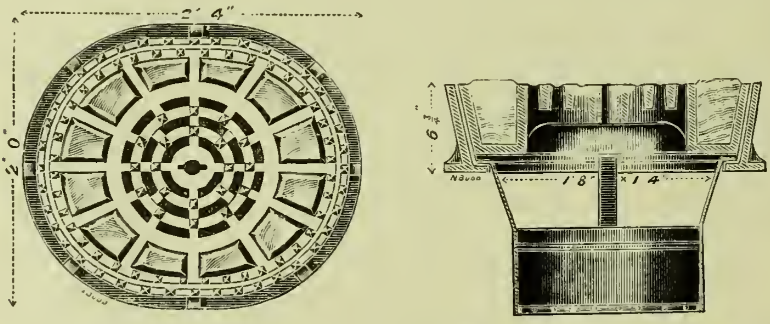


Fig. 176.—Section.

from the upper district shall not tend to increased generation and discharge of foul gas from the sewage. An arrangement for effecting the junction at manholes by means of "syphon" drops, so as to prevent splashing and escape of sewer-gas up branch sewers, is illustrated in Plate IV., page 14.

Simple Ventilation.—Many authorities advocate simple continuous open ventilation, contending that all that is necessary is to dilute sufficiently the sewer-gas with atmospheric air, so as to be able to disseminate it with safety, and at the same time not to cause any nuisance.

This system is thus free ventilation, which, in its simplest form, would consist of an open channel, or a sewer covered with a continuous grating. The flow in such a channel would be liable to be retarded by detritus, etc., falling into it, and thus the openings are restricted to shafts carried up to the centre of the road at intervals, all road gullies being left untrapped,



Figs. 177 and 178.—Bodin's Manhole Cover.

and, in addition, inlets (Figs. 171—176) may be provided in the footpaths and kerbs. The sewer-gas, however, thus given off at the road gratings is often most offensive and dangerous.

Manhole Cover, Oval Ventilating.—A manhole cover of this description, by Messrs. W. H. Bodin & Co., is shown in Figs. 177 and 178. It is fitted with oak blocks and a wrought-iron dirt box.

Elliott's Patent Air Inlet for House Drains.—This air inlet (Fig. 179) has been designed to provide a ready, simple, and cheap method of admitting fresh air to house drains, etc., and is suitable for public thoroughfares. Experience has proved that air inlet gratings when fixed on the surface of the ground are a source of trouble and expense, as dust, sand, and other matters get through the grating and into the trap or drain and cause a stoppage or obstruction. The ventilation of many a good system of drainage is rendered inoperative through accumulations of dirt, etc., blocking up the airholes.

As will be seen by the drawing (section) the air inlet is let into the brickwork—another pattern is also made to be fixed on the face of the wall; the elevation shows the front of the air inlet as fixed; the grating stands five inches above the level of footpath, thus preventing any obstruction to the free current of air to the drains.

These inlets are supplied by Messrs. P. Mooney & Co.

Such openings are affected by fluctuations in the flow of sewage, and also by barometric changes in the atmosphere. Wind blowing over the surface of the ground interferes with the efficient action of these shafts, and tends to drive the foul air generated in the sewer into the branch, or house drains. Objection

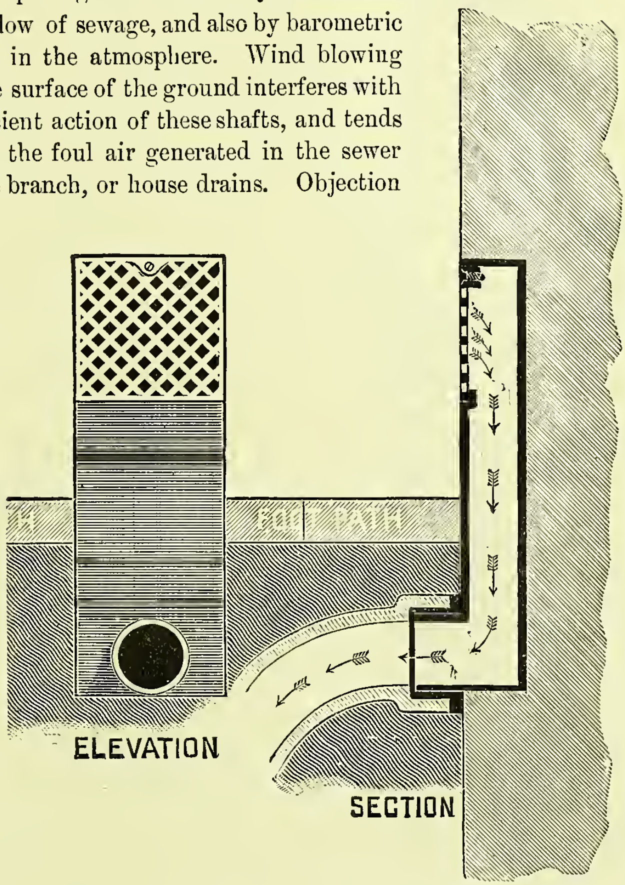


FIG. 179.—Air Inlet for House Drains (Elliott's Patent).

has also been taken to these ventilating openings on account of the sewer-gas escaping into the public thoroughfares.

Ventilating Shafts.—To obviate this disadvantage, pipes not less than six inches in diameter are recommended to be led from the manholes, or shafts, to the gable of adjoining buildings, or to ventilating lamp posts, so as to deliver the foul air at such levels that it may become diluted before it can be breathed (Fig. 180).

There is sometimes a difficulty in placing these pipes in positions where they would prove most useful. They are mostly made of iron, which, however, being a good conductor of heat, act very well during summer or temperate weather, but in cold weather they tend to check the upward flow. Glazed pipes set in cement, and encased in masonry, might with advantage be substituted, but not be built in the walls of dwelling-houses.

Separate inlets at a lower level are also provided for the admission of fresh air, so as to obtain a constant circulation of air. They should also

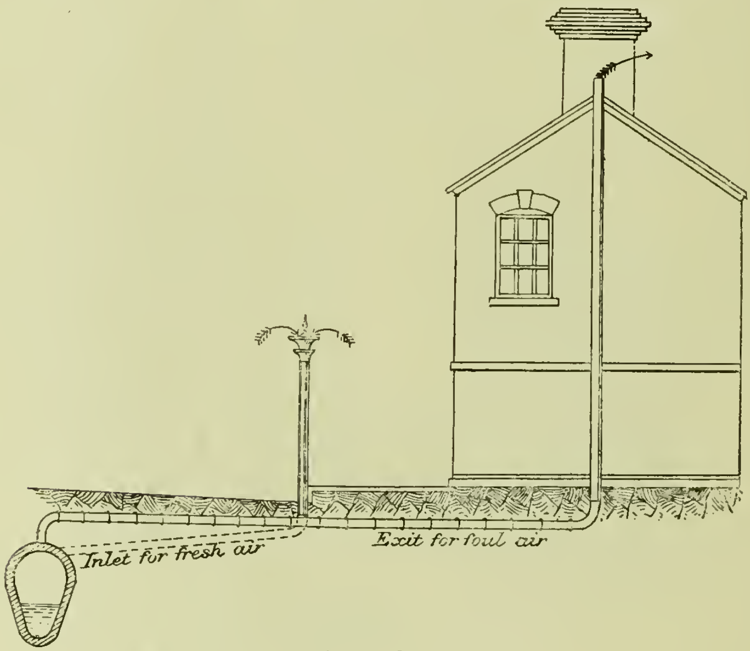


Fig. 180.—Ventilating Opening from Sewer.

be carried up to some height, as, although designed as inlets, the draught may sometimes be in the opposite direction, and thus they will act as outlets.

Velocity in.—Inlets and outlets must, therefore, be considered as possibly acting alternately in any capacity, depending on the amount of friction set up at various times by the flow of sewage.

In designing ventilating shafts, the following points should be kept in view. The frictional resistance of the shaft modifies the current of air very considerably, the amount being in direct proportion to the length of the shaft and inversely as the diameter or area of the tube or shaft; or the same length of tube and velocity of current, the resistance would in a twelve-inch pipe be one-third of that in a four-inch pipe—ventilating shafts should therefore be as large as possible. The frictional resistance also varies directly as the square of the velocity of the current of air.

There is less resistance in shafts of circular section than in those of square section, as the respective friction surfaces are in the two cases as 7 to 8.

Right-angle elbows are found to reduce the velocity in a shaft by one-half, so that a current of air with a 6-feet per second velocity passing up a shaft with two bends would have it reduced to $1\frac{1}{2}$-feet per second, and if in addition there was another bend it would be further reduced $\frac{3}{4}$-foot per second. In order to reduce this loss of velocity to the utmost, where it is not practicable to maintain the shaft in a straight line, the angles ought to be well rounded and as obtuse as possible. The interior surface of ventilating shafts should be made perfectly smooth, so as to reduce the friction to a minimum.

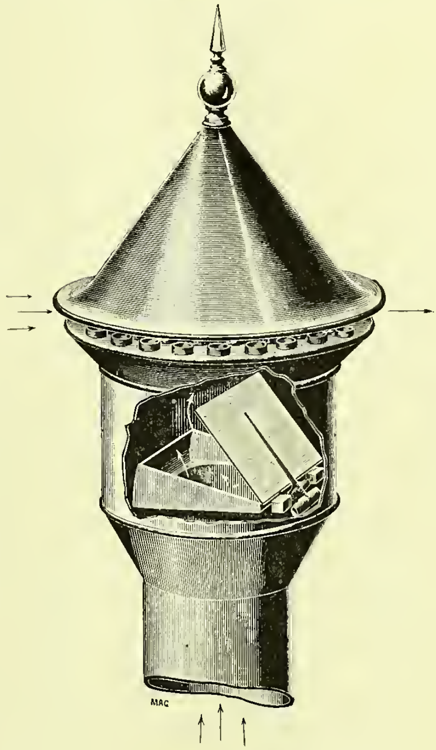


FIG. 181.—Sugg's Up-draught Ventilator.

Formula for.—The following expression gives the velocity of the air current (v) in feet per second, viz. :—

$$v = \sqrt{\frac{\cdot 13\, dht}{d + cl}}$$

where

d = diameter in feet, for shafts of circular section.
= square root in feet of sectional area, for square or rectangular sections.

h = difference in level in feet between the inlet and the outlet of the shaft.

t = number of degrees Fahr. in difference of temperatures at inlet and outlet of shaft.

l = number of feet in length of the shaft.

c = ·02 glazed stoneware pipes.
= ·03 planed wood.

Ventilating Valves for.—It is often necessary to ensure the draught in such channels only acting in one direction. For this purpose ventilating valves are employed of a great variety of patterns. Sugg's patent continuous up-draught ventilator (Fig. 181) is a useful and durable description. It requires no oiling or attention.

Special Arrangements for Dealing with.—Many plans have been tried in order to get rid of the sewer-gas by delivering it in such localities that its dangerous qualities may not be felt, such as lofty shafts, built sometimes in connection with furnaces to increase the up-draught. Such a system promises well for long outfall sewers with no connections, as in the case of the large furnace shaft erected on the Brighton outfall sewer ; the effect, however, on a general system of sewerage, in displacing the foul gas, is small.

High Shafts.—A further attempt in this direction is made by supplying a number of high shafts at different points. By this means a partial clearance is effected. Steel ventilating shafts are made in a great variety of patterns (Fig. 182), from five inches to twelve inches in diameter and up to thirty feet in length from the ground line. The one illustrated is by Messrs. Ham, Baker & Co.

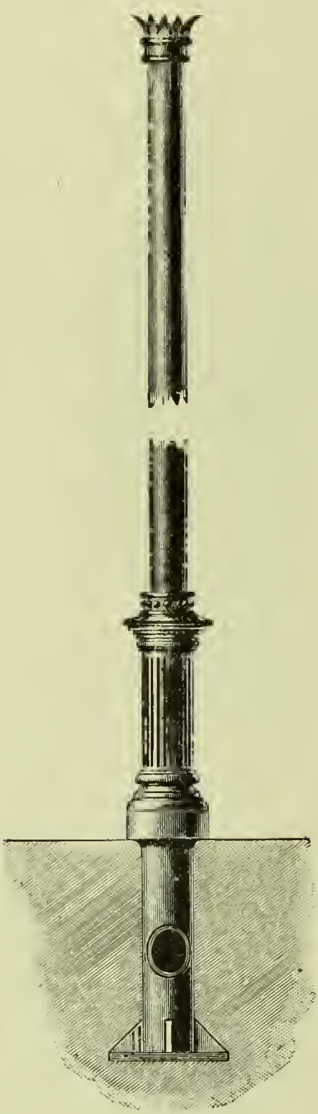


Fig. 182.—Ventilating Shaft.

Other Methods.—Efforts have also been made to prevent the formation of sewer-gas in the sewers ; and when formed, either to neutralize or destroy them. For this purpose absorbent materials, such as charcoal, dry earth, and chemical agents, as well as deodorants and disinfectants, have been placed in the sewers themselves, so as to modify or destroy the noxious properties of the gas. The latter classes of materials have also been applied before the sewage has been allowed to enter the sewer.

Chlorine has even been laid on to the sewers by means of special pipes provided for the purpose ; and galvanic action has also been tried in the sewers, so as to produce ozone from the sewer-gas.

Mr. Dibdin recommends the addition of from one to two grains of solution of permanganate of potash or soda to each gallon of sewage, with the object of keeping it fresh until it arrives at the works.

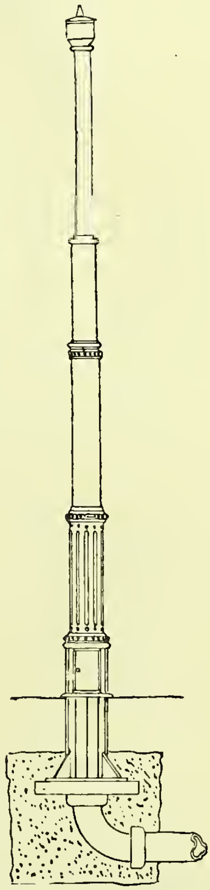


Fig. 183.—Ventilating Shaft with Deodoriser.

Adams's System.—The use of ventilated lamp-hole and manhole covers with absolutely free ventilation at road surface, with disconnecting chambers and cut-off traps for house drains, renders dwellings secure from harm, the gases being liberated outside rather than within. The liberation of sewer-gas, however, does not prevent its evolution, nor compensate for the lack of self-cleansing flow or flushing required by a sewer. Where these considerations have been overlooked, trouble has followed from the noxious emanations which rising from the ventilated cover pollute the air around it.

Charcoal Ventilator.—The charcoal ventilator or trap introduced by Mr. Baldwin Latham was largely used at this time (about 20 years ago) to obviate this ; but as the charcoal to be effective must remain in a dry state, and the moisture from the sewer renders this almost impossible, these gradually went out of use.

Chemical Deodoriser.—A chemical deodoriser brought out by Messrs. Adams followed. In this the sewer-gases passed in their exit through a net of asbestos yarn ; the latter dipping on all sides into a liquid disinfectant, remained saturated, and the gases were more or less deodorised in transit.

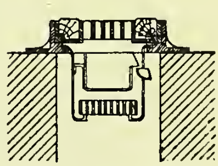


Fig. 184.—Adams's Patent Deodoriser.

Mr. W. Santo Crimp's Experiments.—Experiments made, notably by Mr. Santo Crimp, tend to show that the direction and force of the wind is the principal factor to be dealt with in sewer ventilation ; that ventilating openings or ventilating columns may act either as inlets or outlets, according to the condition of the wind for the time being.

Keeling's Gas Destructor was at one time largely used. He employed a modification of the Bunsen burner to heat a metal surface

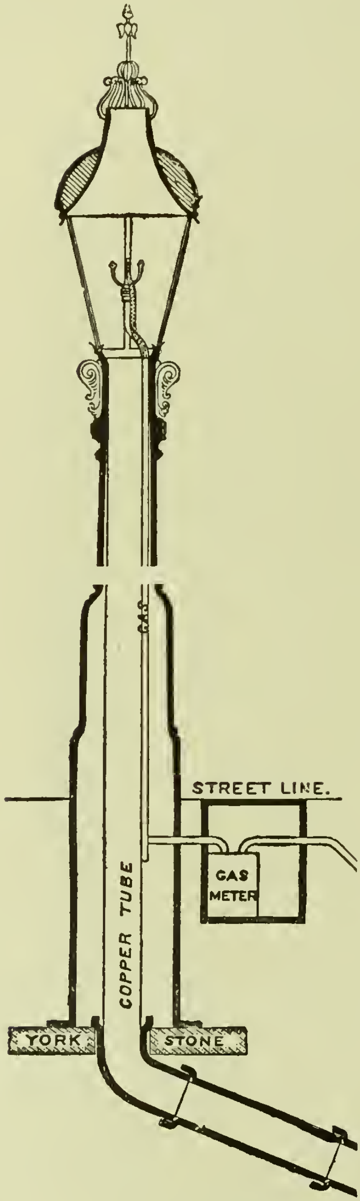


Fig. 186.

Fig. 185.—Sewer-Gas Extractor and Destructor (Webb's Patent).

within a column, up which the sewer-gas travelled. The gas was absolutely cremated in transit, and an upward current aided if not ensured.

Many varieties of columns are in use, with and without special burners.

Adams' Ventilating Shaft.—Fig. 183 (page 273), shows a simple ventilating column, either fitted with or without a deodorising apparatus, which is inserted within the base of the column, through a small door provided for this purpose.

Fig. 184 shows one form of deodoriser where a chemical block is used in lieu of the liquid disinfectant already described.

The Reeves System of Sewer Ventilation.—This system is fully described on pages 288—288F at the end of this chapter.

Webb's Patent Sewer-gas Extractors and Destructors.—It is claimed that by the use of this patent sewer ventilation may be effected with increased light from the street lamp (Fig. 185), and without any increase in cost for gas. It is in use at the Strand (London), Tottenham, Hereford, Southampton, Wolverhampton Hospital, Tettenhall, Abergavenny, Leicester, Malvern, Leamington, Paris, etc., and is supplied by Webb's Engineering Co., Ltd.

Water Injection.—In some cases water has been injected into the extracting shafts so as to absorb the gas.

Machinery.—Fans driven by machinery have also been used to extract the foul air.

Shafts for Ventilating, Size of.—Ventilating shafts and pipes should be of the same sectional area as the drains they are intended to ventilate, and should have as few bends as possible.

Pipes for.—Heavy cast-iron pipes for sewer ventilating shafts, soil-pipes, etc., as shown in Fig. 186, are made by Messrs. Ham, Baker & Co., with bends. junctions, etc., in accordance with the London County Council regulations, of the following weights :—

Inches.		Weights per 6 feet Lengths in lbs.	Inches.		Weights per 6 feet Lengths in lbs.
$3\frac{1}{2}$	...	48	5	...	69
4	...	54	6	...	84

This pipe is made strong enough to be caulked in the same manner as ordinary cast-iron water pipe, and can be supplied with ears if desired.

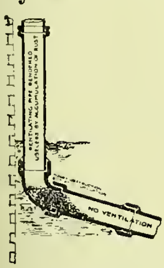


Fig. 187.—Accumulation of Rust in Ventilating Pipe.

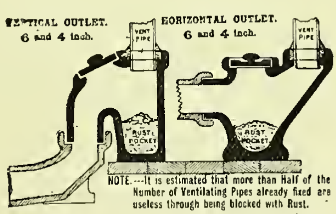


Fig. 188.—"Loco" Rust Chamber.

Rust Pockets.—On account of the tendency to corrosion, all iron ventilating pipes should be provided with a rust pocket. Ventilating pipes, being generally of cast iron, soon become coated internally with rust scale, which falls within the pipe and accumulates at the first bend, or at the junction of the pipe with the drain (Fig. 187), often forming a complete stoppage, and arresting ventilation. Two patterns of "Loco" rust chambers are shown in Fig. 188, and are so arranged that the rust falls into a pocket specially formed for its reception, thus leaving the way clear for the passage of air ; the rust can be cleared out occasionally by the hand hole. A special arrangement on the same principle is supplied by Mr. Lynde, by use at bends on an iron pipe.

Intercepting Traps.—[For object of traps generally see Chap. VIII.] Traps, employed to disconnect the house drain from the main sewer, are called intercepting traps.

Single Drainage.—In the case of a town, all house drains should be cut off from the sewer by means of an *intercepting* trap or syphon, etc. (Figs. 223 to 250, pages 292 to 299), care being taken to provide independent ventilation for them.

Combined Drainage.—A combined drain is generally considered to be a small pipe or culvert conducting the drainage of two or more houses to the sewer. It should be aerially disconnected from the house drains discharging into it, otherwise there is a danger of infection spreading from one house to the other in consequence of the possible dissemination of germs by the splashing of the vertical soil-pipe of the house infected ; in the presence of hot vapours there would be a tendency to convey them upwards, and through any defects in the arrangements with the other houses. A combined drain unless protected in the manner indicated is more dangerous than a sewer, as there is greater probability of the survival of specific organisms in it than in a sewer, on account of its proximity to the house. To enable this disconnection to be properly effected, they should run entirely outside houses and at such a distance from them as to admit of the drains from the houses being efficiently disconnected from them. For the same reason where drains from several houses are led to a junction pit or manhole before discharging into the sewer, the disconnecting syphons should be placed between the manhole and each house ; the manhole itself may be fitted with an air-tight cover and a pipe led from it to a shaft up one of the buildings, so as to ventilate the sewer.

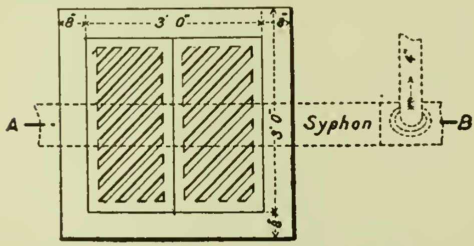


Fig. 189.—Plan of Disconnecting Pit.

In order to disconnect the combined drainage of any group of houses from a main sewer, a disconnecting pit is necessary, such as that shown in Figs. 189, 190. Any number of drains may be collected into this pit, as shown in Figs. 191, 192. It should be covered with a perforated grating, or fresh air may be admitted to the pit by a special inlet shaft. Rogers Field's, and Crapper's improved Kenon (made also by Joseph Cliff & Sons, Fig. 238, page 296), have some advantages, and are intended to be used in connection with a manhole, so that they may be readily cleared of any obstruction.

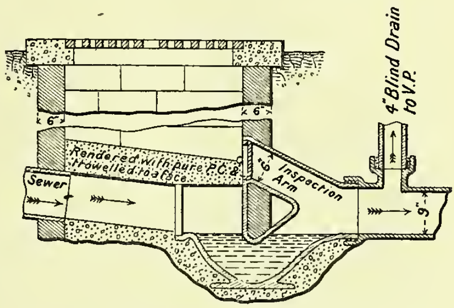
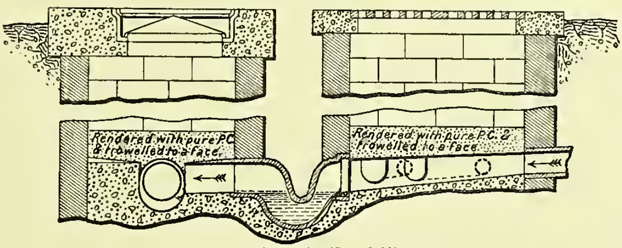


Fig. 190.—Section on line A. B. of Fig. 189.

In Figs. 191 to 193 the application of this trap in an improved manhole



Section on line C. D of Fig. 192.
Fig. 191.—Disconnecting Pit for a Series of Pipes.

is given. The small chamber on the upper level is intended to intercept road detritus, and thus prevent the drain from getting choked.

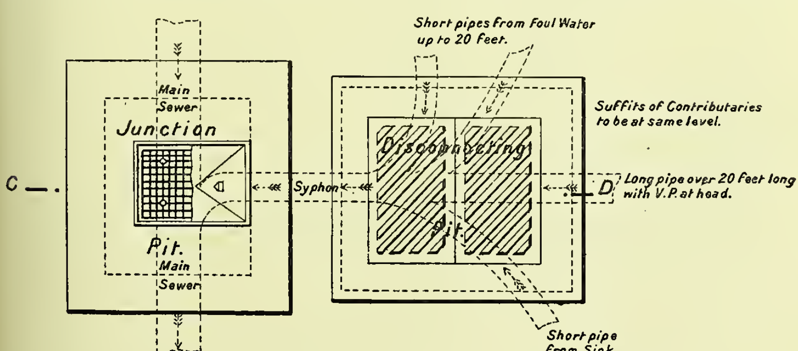


Fig. 192.—Plan of Disconnecting Pit for a Series of Pipes.

A great variety of traps suitable for the disconnection and ventilation of soil-pipes are shown in Chap. VIII. (Figs. 223 to 250, pages 292 *et seq.*), and for use in connection with disconnecting pits in Figs. 237 to 243 (pages 295 to 298).

Care must be exercised in locating such pits, as for the reason already stated sewer-gas may be emitted from them when liquid is being discharged through the drain.

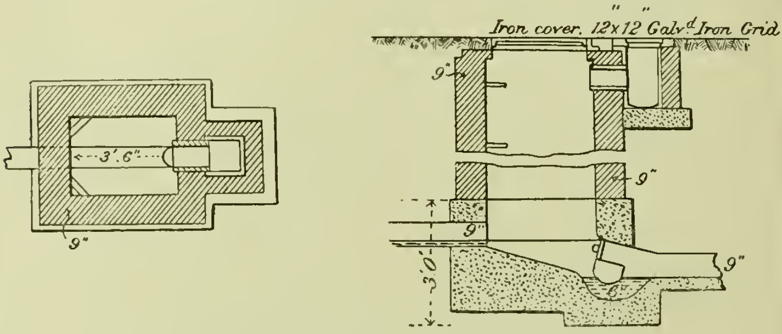


FIG. 193.—Manhole with Kenon Intercepting Trap fixed.

House Drainage.—In the case of a single house, instead of a disconnecting pit, a syphon and fresh air inlet might be used, as shown in

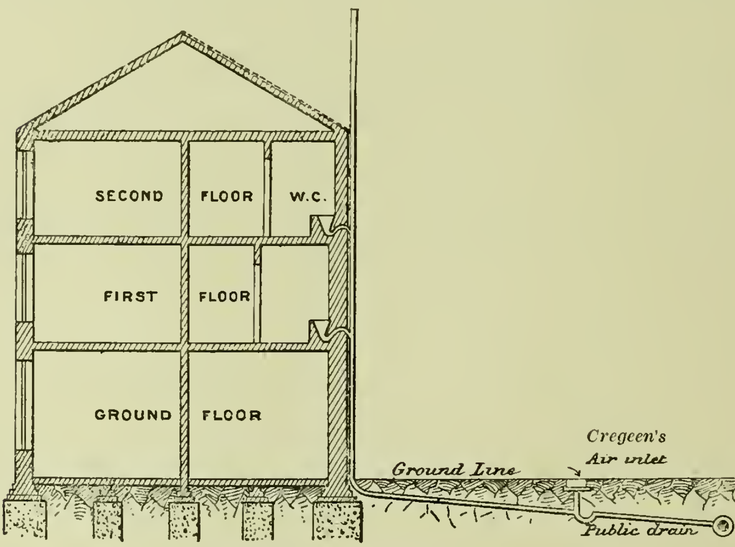


FIG. 194.—House Drainage: Syphon and Air Inlet employed instead of Disconnecting Pit.

Fig. 194. There should be as few connections between the house and the drains as possible, being practically limited to that necessary for the w.c. apparatus; and with this single exception, all wastes from cisterns and

safes should discharge into the open air, and those from baths, ablution ranges, and sinks should deliver over a trap, or a properly constructed channel leading to a trap, and on no account be directly connected with the drains in any way whatever (see Plate XV., page 280).

Soil-pipe, Ventilation of.—The soil-pipe should be continued above the eaves of the roof as a ventilator (of the dimensions given in chapter on Construction), avoiding bends as much as possible; the extremity should be situated well clear of flues, dormer windows, etc. The difference between the temperatures in the bottom of the shaft and at the top is generally sufficient to maintain a draught in the pipe, and this is accentuated if the wind is allowed to blow freely over the open end. For this reason, any covering is objectionable, but it is generally found advisable to use a copper wire netting to prevent birds from building in the opening. It is sometimes necessary, when the natural action is insufficient to induce an upward current of air in the ventilating pipe, to employ a cowl; in that case the ventilating pipe must be carried up above the ridge so that it may be fully exposed to the action of the wind from any direction. When there is no wind some descriptions of cowls have a tendency to check whatever natural draught would otherwise exist.

Alternative Method.—When the extremity of the extracting shaft carried up from a soil-pipe would be situated dangerously near windows, flues, etc., and the length of drain to be ventilated is considerable, it becomes necessary to place a syphon at the foot of the soil-pipe, a false drain being led to a convenient position for the extracting shaft, as shown in Plate XVI.

Fresh Air Inlet to Soil-pipes.—Under such circumstances the soil-pipe itself still requires ventilation, and with this object a fresh air inlet must be provided on the house side of the trap, by using one of the *ventilating intercepting traps* shown in Chap. VIII. Buchan's, Weaver's and Hellyer's traps (Figs. 223 to 236, pages 292 to 295) are well adapted for the purpose.

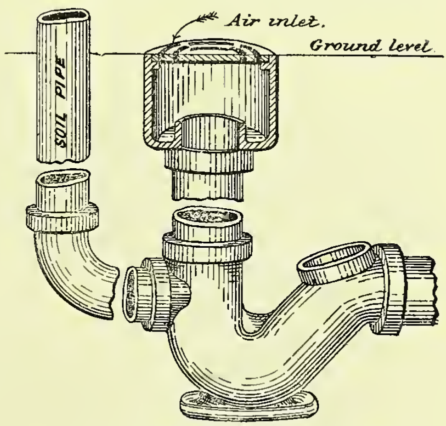


FIG. 195.—Cregeen's Patent Air Inlet.

Cregeen's Patent Air Inlet (Fig. 195) has some special advantages. The grating covering the fresh air inlet is made solid immediately over the opening to the shaft, and thus prevents dust and dirt falling into the bend ; the cover can be readily moved for the purpose of clearing the annulus when necessary. It is supplied by Messrs. Duckett & Co., and Stone & Co.

The inlet for fresh air thus provided at the foot of a soil-pipe is liable to emit foul air, especially when a discharge of liquid takes place in the pipe. In many places it would be dangerous to run the risk of the foul air, generated in the vertical soil-pipe, being given off in such a locality. To obviate this the inlet may be carried up a few feet above the ground, away from doors and windows, and protected by a mica flap inlet ventilator, as shown in Fig. 196, or a false drain (Plate XVI.) may be led some distance away, and provided with a suitable inlet; the flap closes with the slightest up-draught.

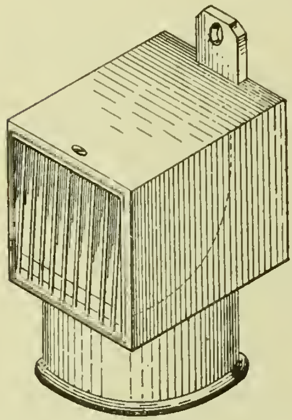


Fig. 196.—Mica Flap Inlet Ventilator.

The drain-aerating inlet valve (Figs. 197, 198), Simmance's patent, commends itself both from appearance and design as very efficient. There is nothing objectionable in its appearance, and as the valve ports are hidden, there is no temptation to mischievous persons to tamper with the valves.

Beaumont's Patent Valve.—This is shown in elevation in Fig. 199, and in section in Fig. 200, as inserted in Cregeen's air inlet cover. The valve is made of cast iron of such a size as to fit into the 6-inch pipe of the air-inlet cover. On the lower end are fitted two flat valves of aluminium, which allow fresh air to enter the drain pipe, but will prevent any back flow of sewer-gas. This arrangement allows surface air-inlet covers to be fixed near buildings, and in such a manner as to effectually prevent the valves from being injured. Ham, Baker & Co. are the manufacturers.

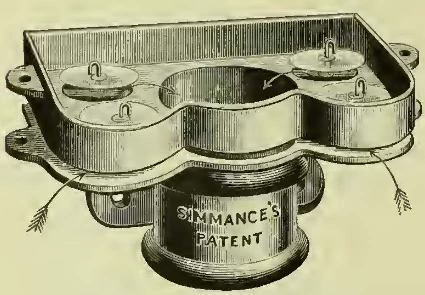
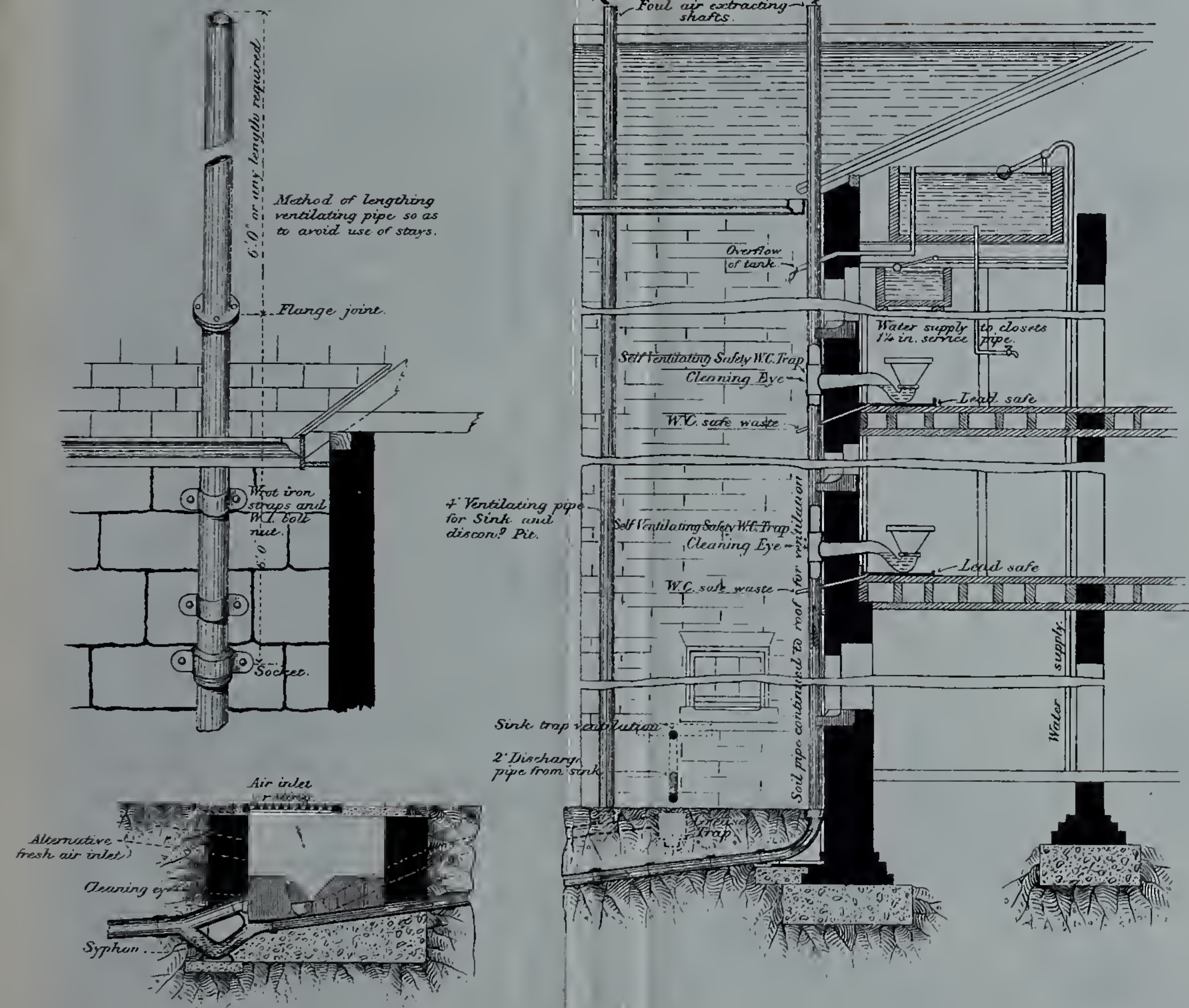


Fig. 197.—Simmance's Drain Aerating Inlet Valve (Interior of Valve Box).

Cowls.—These appliances are intended to control the direction of the current, and ensure the air in the drain flowing in one direction. They

VENTILATION OF HOUSE DRAINAGE

PLATE XV.



J. Akerman Photolith London

FALSE DRAINS

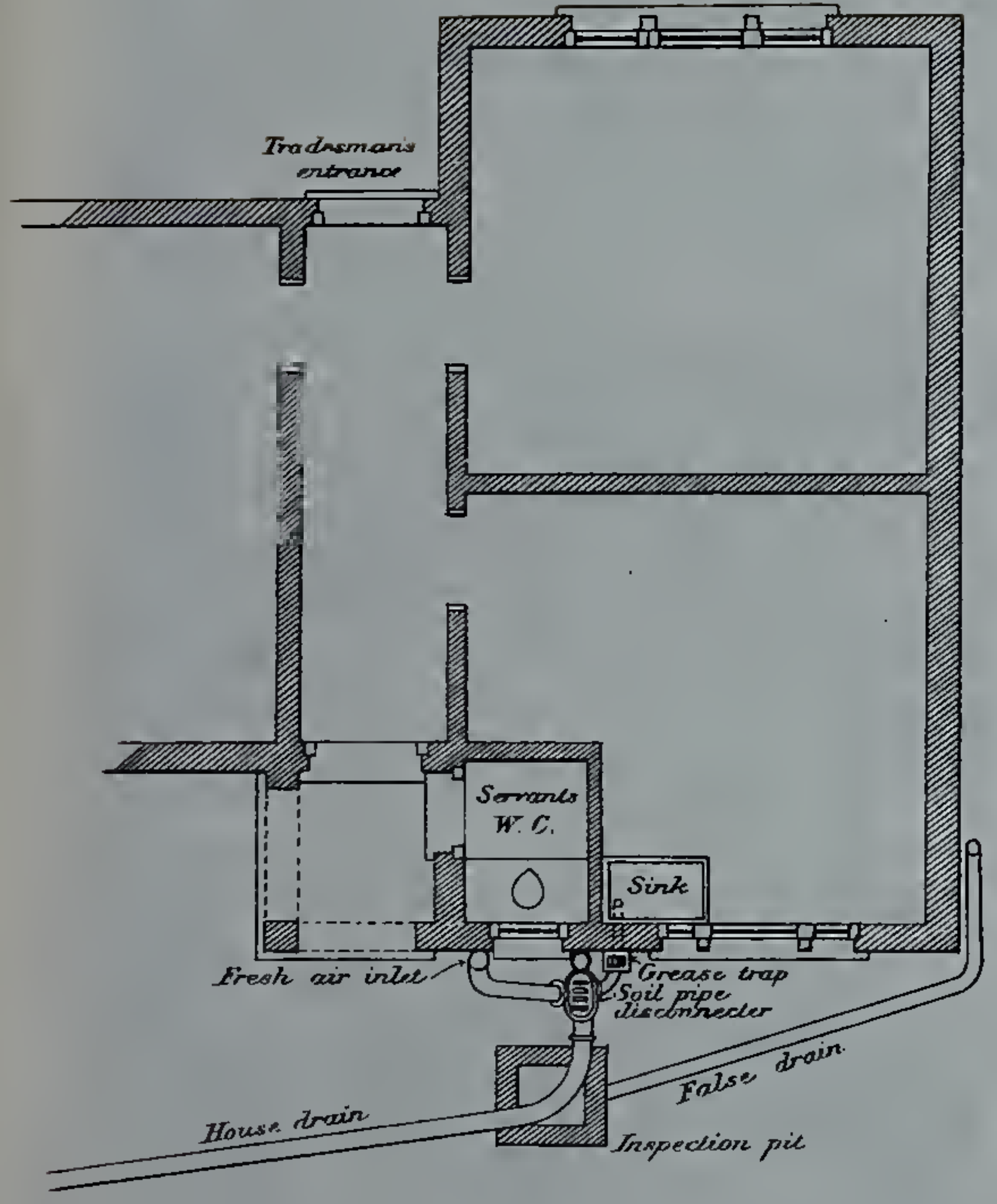


Fig. 1.

Fig. 2.

may be of use in special cases, but many advocate the ends of inlet and extracting shafts being left open without a cover of any sort, except an open copper ball netting, to keep birds from affecting the outlet.

Very excellent cowls have been designed by Messrs. Kite, Boyle, Hellyer, Buchan, Banner, Weaver, etc., a few of which are shown in Figs. 201 to 205.

A down-cast ventilator by Kite is shown in Fig. 206.

The "Empress" revolving cowl is set in motion by the wind. Its action is explained by reference to Fig. 207. It requires to be lubricated periodically.

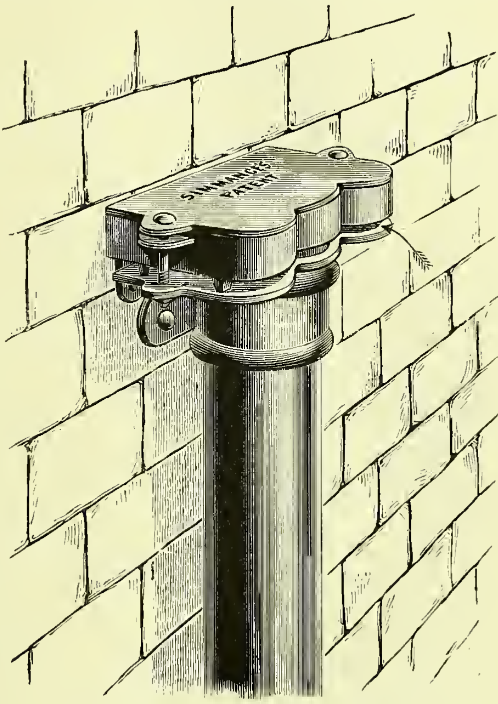


FIG. 198.—Simmance's Drain Aerating Inlet Valve (Exterior).

Sugg's Patent "Continuous Up-draught" Ventilator.—This cowl is brought into action by the wind blowing across the short tube (Fig. 208) immediately

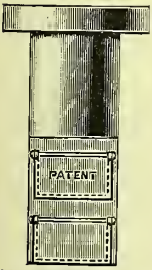


FIG. 199.—Beaumont's Patent Valve.

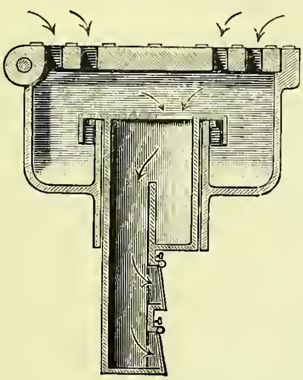


FIG. 200.—Beaumont's Patent Valve with Cregreen's Air Inlet Cover.

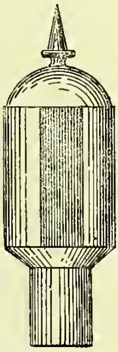


FIG. 201.

beneath the flat bottom of the conical cover, inducing an upward current of air; the whole area of the ventilator is acted upon at the

Ventilators and Cowls.

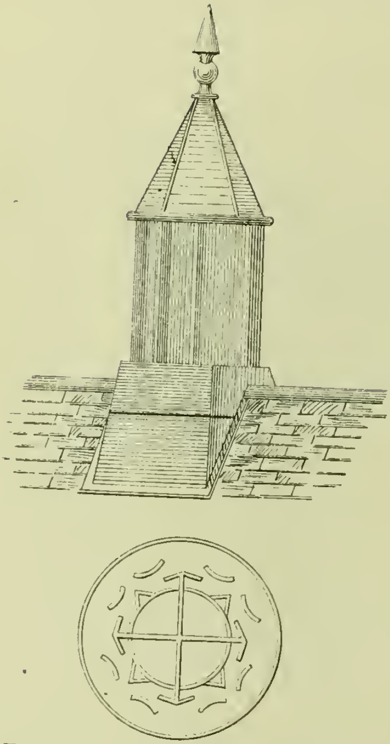


Fig 202.—Boyle's Air-Pump Ventilator, with Plan.

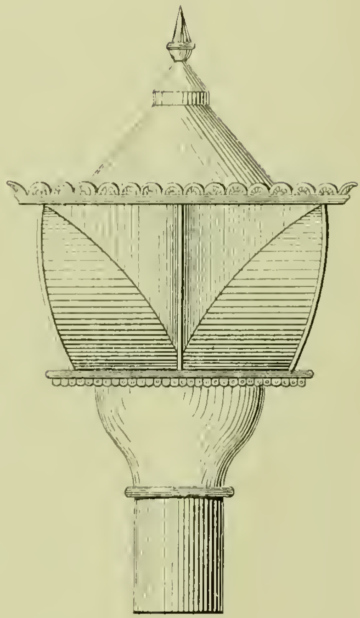
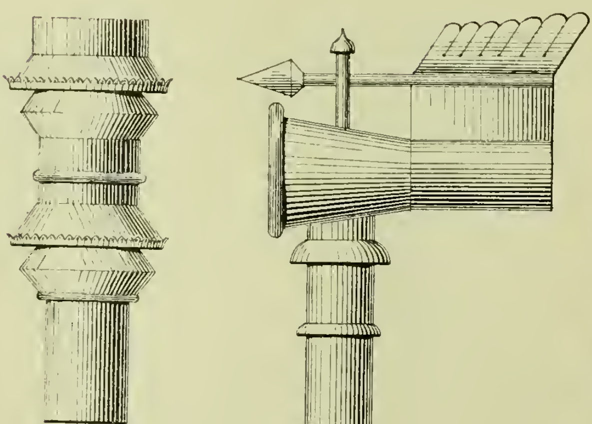


Fig. 203.—Banner's Patent Inlet Cowl.



Figs. 204, 205.—Banner's Patent Outlet Cowls.

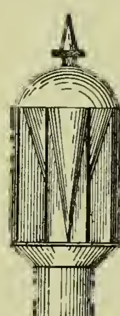


Fig. 206.—Kite's Down-cast Ventilator.

same moment, and the cowl is kept in action, no matter which way the wind is blowing. The ventilator is noiseless and absolutely weather proof. An addition of a gas jet is shown in the figure fitted in the shaft, and is intended to assist ventilation ; it is invaluable where there is no wind. It is stated that this ventilator, on a shaft eight feet long, fitted with a small gas burner, as described, will in a perfectly still atmosphere extract 2,500 cubic feet of air per hour where the diameter of the shaft is six inches, and 5,000 cubic feet per hour with a 9-inch shaft ; the assistance of a moderate wind greatly increases the amount of air extracted.

Wastes from Sinks, Baths, etc.—Wastes should be trapped under the fitting, but in some cases pipes discharging from sinks have been known

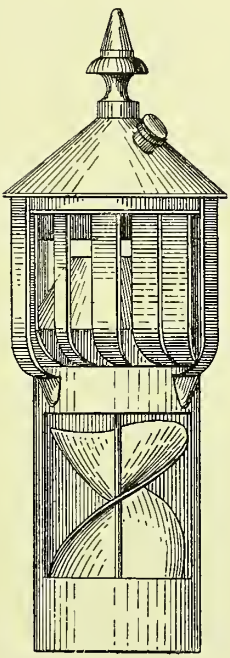


Fig. 207.—"Empress" Revolving Cowl.

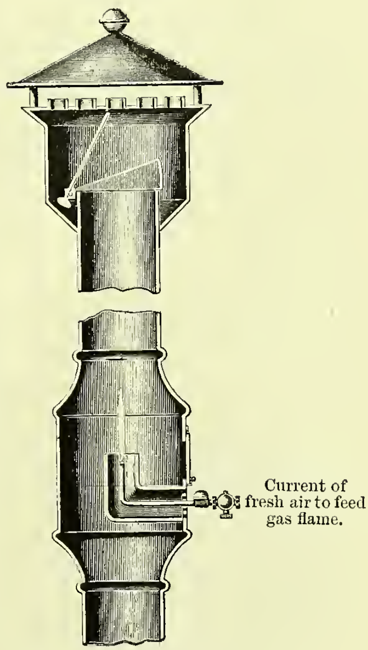


Fig. 208.—Sugg's Ventilator.

to become untrapped, and then, even if disconnected from the drain, an unpleasant smell from the pipe itself will enter the house. If, however, the method of ventilation shown in Fig. 209 be adopted, this danger will be avoided.

Water from baths and lavatories situated on upper floors should be led by the waste through an external wall, and the pipe continued without break to the ground level and made to discharge in the open air, either with a channel leading to or over a trapped gulley ; and the pipe should be continued upwards as a ventilator, the requirements being so far similar to those of a soil-pipe.

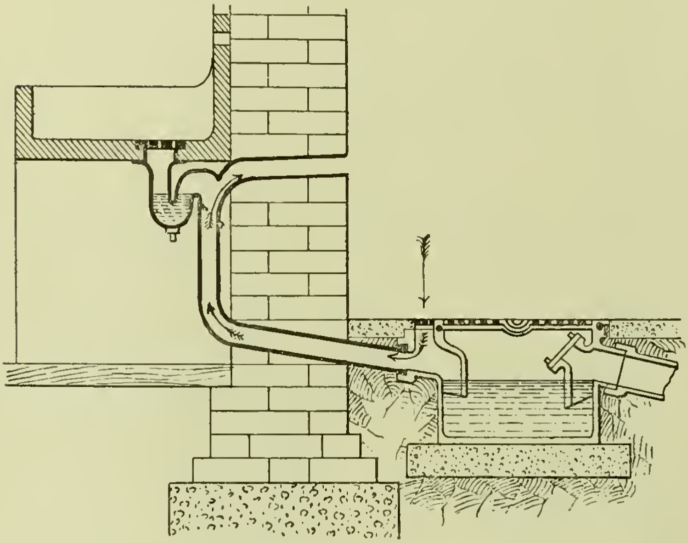


Fig. 209.—Ventilation of Sink.

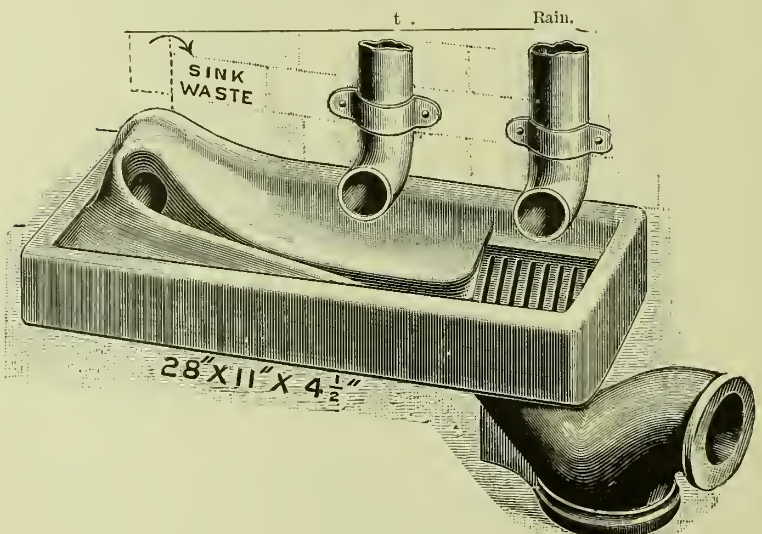


Fig. 210.—Ducketts' Self-cleansing Channel Gully.

Ducketts' Patent Self-cleansing Channel Gully is represented in Fig. 210. Its use prevents any tendency for the sewer-gas escaping from the gully to pass up the wastes from the sink, bath, etc. ; it is a very convenient and sanitary arrangement.

Mooney's Patent Self-cleansing Gully Block.—This is shown in Fig. 211. It is intended to prevent the possibility of sewer-gas passing up the waste pipes by keeping the entrance to the trap some distance away from the foot of the wastes; and it is claimed in addition that it avoids splashing and running over, and the grid is so made, that a filthy deposit round it cannot take place.

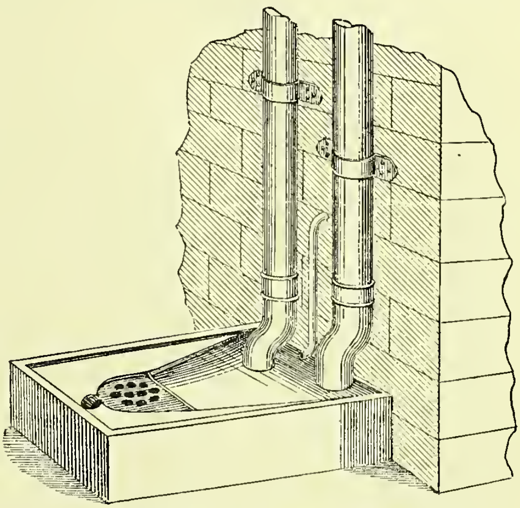


Fig. 211.—Mooney's Self-cleansing Channel Gully.

Sykes' Patent Disconnecting Slipper (Fig. 212) is intended for the discharge of sink and other waste pipes eighteen inches from the gully, so as to prevent noxious gases escaping through the pipes into the dwelling. Sykes' slipper effects this, and prevents all splashing, and at the same time acts as a gully and

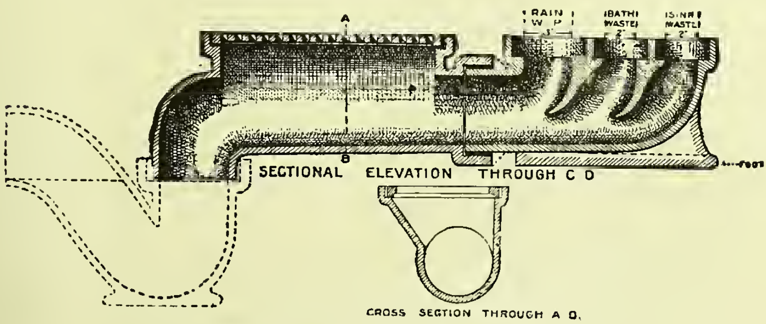


Fig. 212.—Sykes' Patent Disconnecting Slipper.

disconnector combined. It is provided with sockets at one end for either one, two or three intakes according to circumstances, and can be used in connection with an ordinary S or P trap.

Outside Gullies.—Outside gullies for receiving slop water from sinks should be ventilated, and for this purpose, from the drain side of these gullies, a ventilating pipe, 4-inch diameter, should run up above the eaves of the roof, as shown in Plate XV. (page 280). The joints of such pipes should be air-tight.

Yard and parade gullies for surface drainage cannot well be ventilated, and for this reason the separate system should, if possible, be adopted, such gullies being thus kept distinct from the sewerage system.

Ventilation of Drains of enclosed Blocks of Buildings.—Where practicable, it is advantageous to disconnect the several sections of a series of drains, pipes, and sewers in such a manner as to prevent an accumulation of foul gas. Plate XVII. represents blocks of buildings in an enclosure, and the drainage therefrom. Such a system should be considered as one of house drainage, the ventilation being provided at the upper end of each branch (as shown at V). A disconnecting pit might be placed at point N, through which air could be admitted by an open grating covering the pit, or by means of a large pipe led up, or a chamber cut in, the brick wall. All changes of direction should be made in the small junction pits (marked JP). The drainage of the stable at B should be led by means of surface channels to a trap of the form shown in Figs. 264 to 267 (pages 303 to 305), twelve feet clear of the building, and be successively disconnected from the other drains as far as possible. M is a manhole on the town sewer Z, into which should be led the drain-pipe from the blocks, and if proper means of ventilation were provided at this point (M), there would not be sufficient pressure of sewer-gas to force the disconnecting trap of the main enclosure drain.

Drains under Buildings.—Where from the necessities of the case drains have to be laid in this position, they should be carefully constructed as described in Chap. VI. (page 255), and fresh air admitted freely at either end of the pipe. With this object in view, it should be disconnected from the sewer at the lower end by means of a syphon, and an inlet for fresh air provided; at the upper end there should also be a fresh air inlet and a flushing tank to keep it perfectly clean (*vide* Plate XVIII.). Sykes' patent interceptor (Fig. 240, page 297), made by the Albion Clay Co., might be used with advantage in this connection.

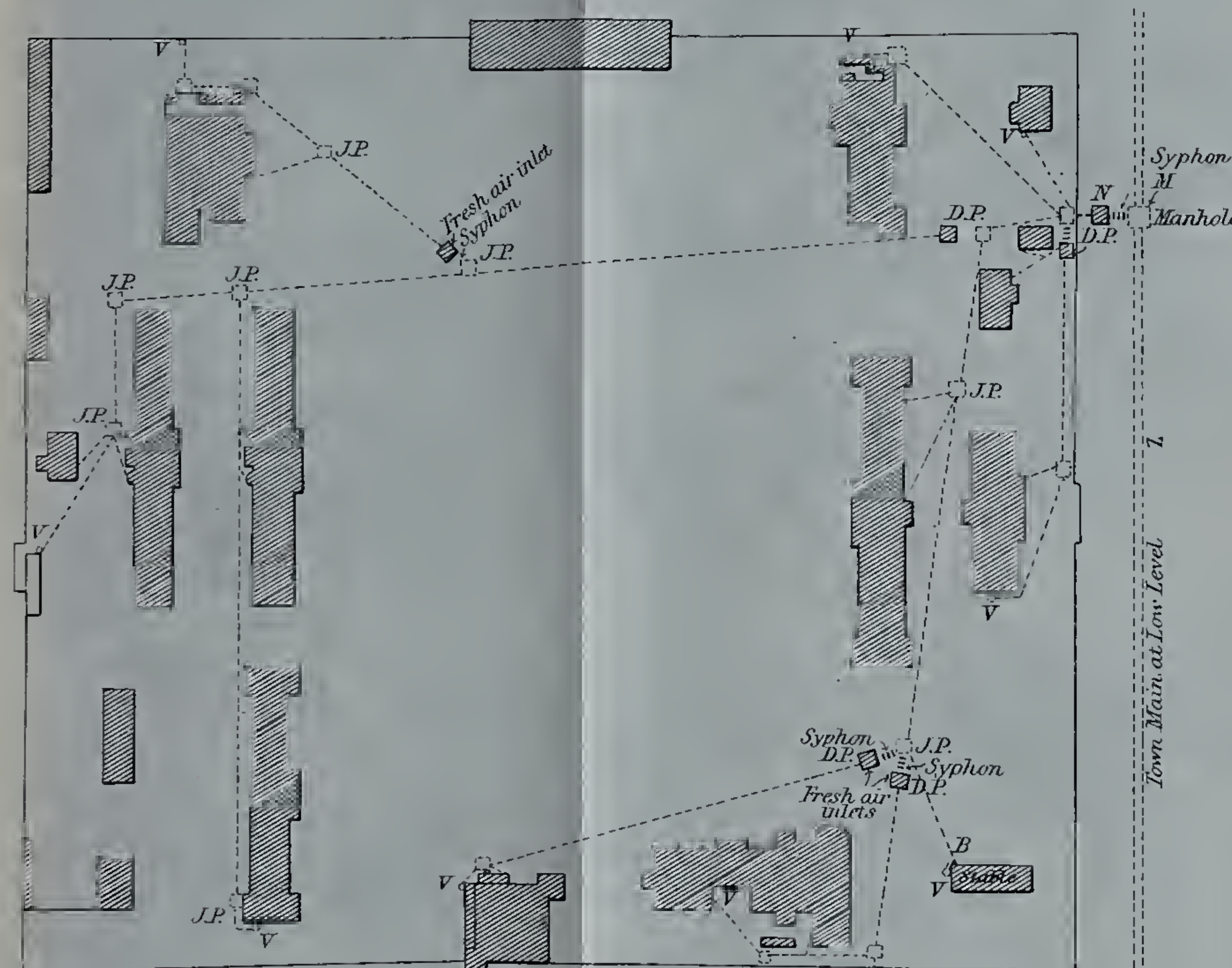
Admission of Surface Water to Foul Drain.—It is often desirable to admit a certain amount of surface water to a sewer, and as the supply is as a rule intermittent, there is a chance of a trap as usually supplied running dry: this is obviated by the arrangement shown in Figs. 213 to 216.

Public Conveniences (Underground).—The ventilation of these places (page 342) as arranged by Mr. George Jennings is provided for by the passages for ingress and egress, and in addition a lamp column is used in conjunction with air propellers for the removal of vitiated air.

PLATE XVII.

USE OF JUNCTION PITS &c.

Junction pits .... J.P.
Disconnecting pits ..... D.P.
Ventilators .... V.

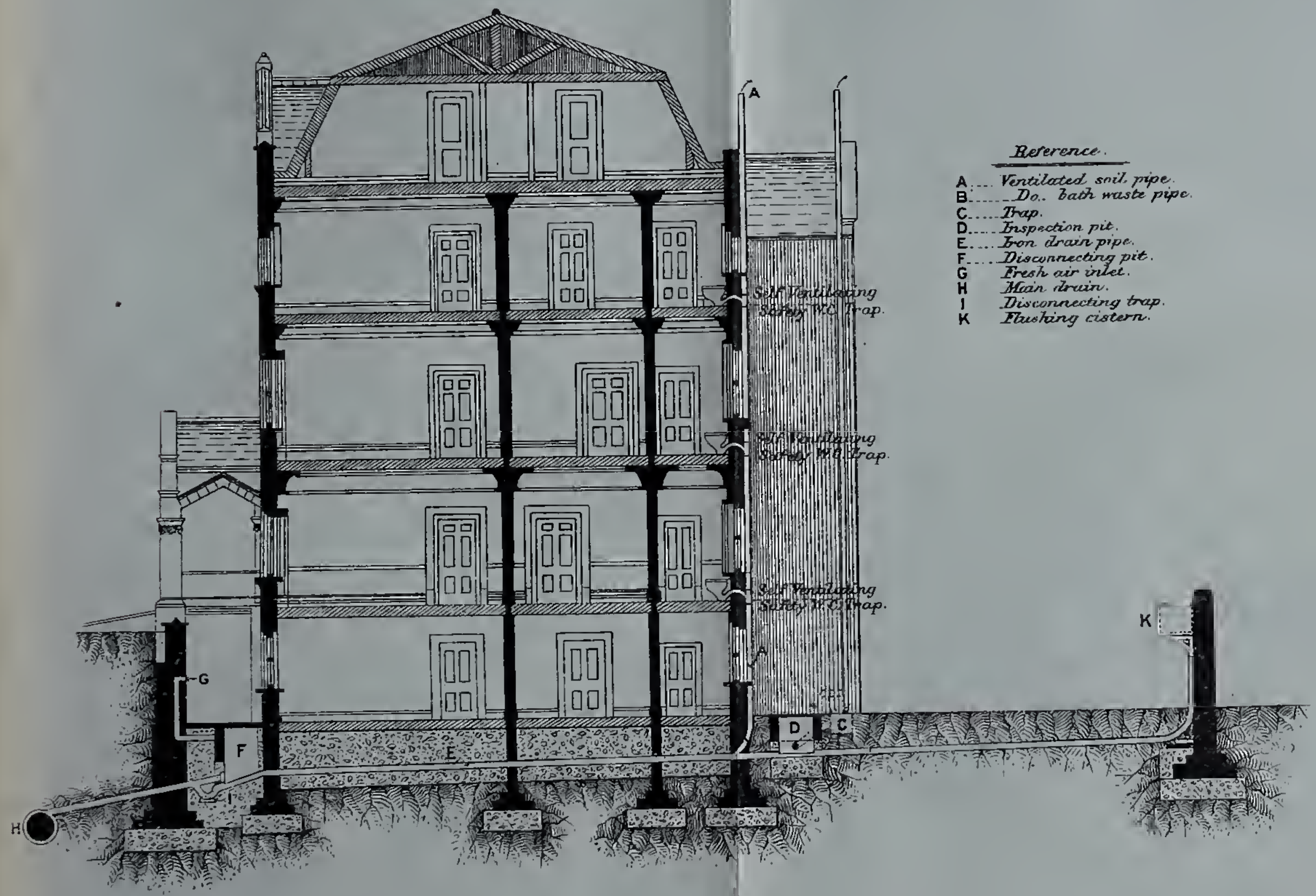


J. Akerman, Lith. 6, Queen Square, London W.C.

PLATE XVIII.

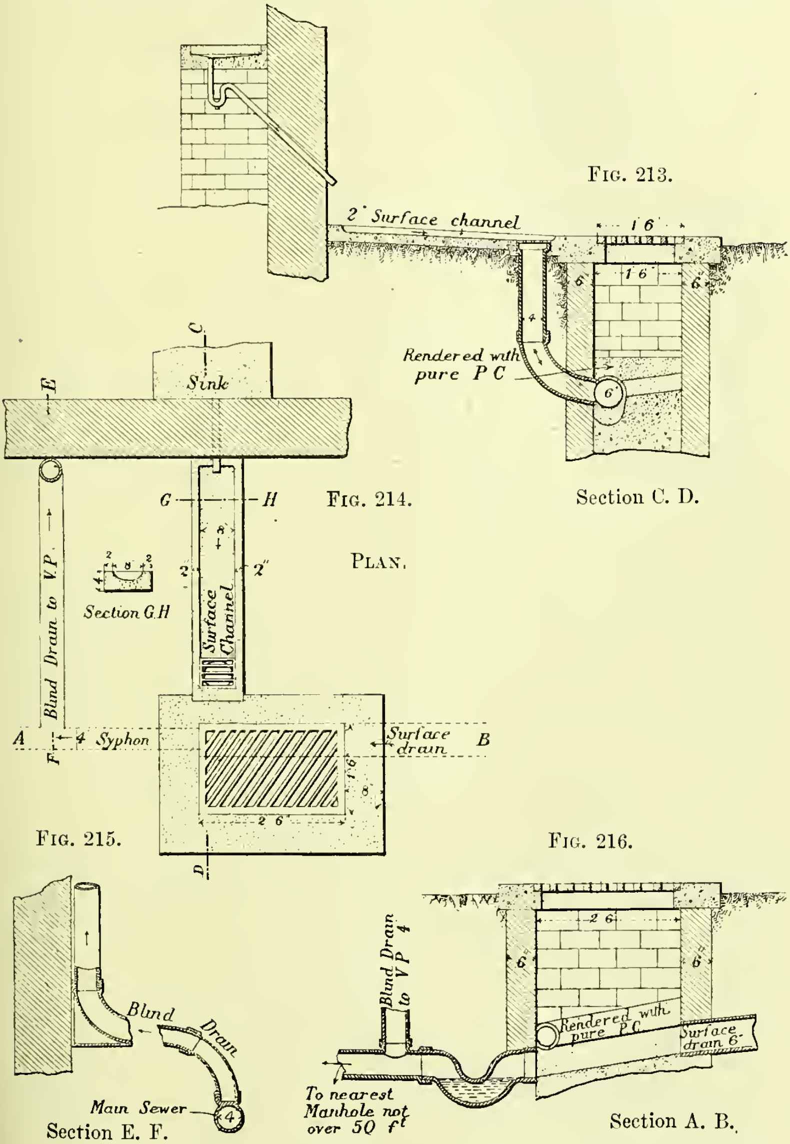
HOUSE DRAINAGE.

Showing arrangement to be adopted when drains are carried under houses.



J. Akerman Photo-lith London

It has perforated panels in the base, as well as slotted openings at the top; these are necessary for the proper exit of the extracted air; and it



Figs. 213—216.—Arrangement for Admission of Surface Water to Foul Drain.

is also best to have top and bottom openings to prevent anything like resistance occurring by the passage through, or partial imprisonment within, of the air in the column. The fan used by Mr. George Jennings is the "Blackman," and is water driven. The fan has the water motor combined with it, and made part of the apparatus, which is a more convenient arrangement than when the fan and motor have to be distinct and separate. As a rule the pressure of water obtainable is about 30 lbs. per square inch, which is sufficient to drive the fan at its proper speed, in which case an 18-inch size will remove approximately 3,000 cubic feet of air per minute; while a 24-inch is capable of extracting about 5,000 feet. The fan should be situated at a point where it will most readily and equally cause the vitiated air to pass to it; and as a rule this point is necessarily as far removed as possible from where the fresh air enters, or can enter.

Sewer Ventilation—The Reeves System.—This system is intended to produce oxidation of the sewer air by artificial means when the natural oxidation fails, and it is claimed by the inventor that the method advocated is thoroughly practicable and at the same time economical. The sewer gases as generated are destroyed in specially prepared manholes by the aid of chemical apparatus, whilst, at the same time, the decomposition of the sewage is arrested, and the necessity for the provision of expensive ventilating shafts is done away with.

The following is the theory of the system :—

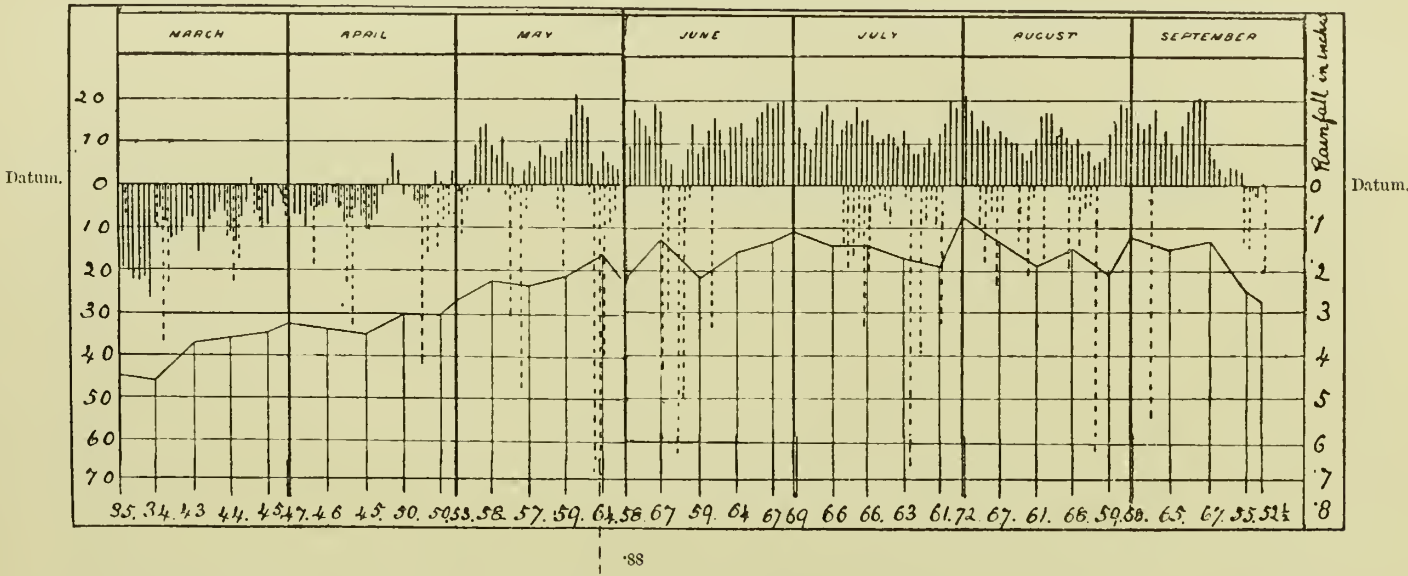
Sewage in transit through the sewers ferments and gives off gases which become progressively noxious and dangerous. The average amount of this gas which bubbles up from the sewage into the sewer air in the case of London is estimated to exceed 3,000,000 cubic feet daily; the whole of this dangerous product can be neutralised if, as it forms, a sufficient quantity of fresh atmospheric air is allowed to mix with it, so as to procure natural oxidation.

A system of gratings level with and fixed in the centre of the street at intervals, in their due proportion, is the best means of effecting natural oxidation, and so long as sufficient fresh air *goes down* by these gratings the sewer air remains "sweet." The essential thing, therefore, in sewer ventilation is to get the fresh air *down*, not to get bad air up. *In a properly ventilated sewer there should be no bad air to come up.*

Natural oxidation is, however, limited by certain atmospheric conditions; for instance, in the case of the London sewers, the average temperature is about the same both in summer and in winter, and may be taken as ranging between 52 and 55 degrees. So long, then, as the surface temperature is sufficiently low to make the outside air denser than the air in the sewers, natural oxidation will go on, as the heavier atmospheric air will descend through the lighter sewer air and diffusion will ensue.

When the outside temperature, however, rises to, say, 65 degrees, 70 degrees, or even higher, then natural oxidation becomes inadequate and sometimes impossible. Notwithstanding the efforts that have been made in recent years to improve sewerage, yet there are very few towns of which it can be said that the sewers are at all times properly ventilated, and this applies more especially to the summer months of the year. On reference to the chart (Fig. 186a) it will be seen that the air in the sewers during the month of March, 1889, was heavier than the outside air on one day only, but the rainfall would more than counterbalance that, as large quantities of air enter the sewers with the inrush of water from the surface. The rainfalls noted would produce such inrushes, in addition to which the rainfalls would cause first of all a displacement of bad sewer air, and secondly, this displacement of bad air would be replaced to a great extent by fresh air when the sewage level fell again. Towards the end of April the manufacture of sewer-gas would begin. There was a pressure on the surface gratings in the month of May on two days only, but the frequent rainfalls supplied fresh air in sufficient quantity to prevent the production of sewer-gas becoming very dangerous, and in the month of June, during the first six days, when gas would be forming very rapidly, its bad effects are modified by the rainfalls between the 6th and 12th. For 22 days following, there being no rainfall, the manufacture of sewer-gas went on uninterruptedly, and a highly dangerous development was reached, gas of the worst description being now contained in the sewers. On the 27th June, two workmen went down a sewer in Stamford Street, Waterloo Road, and nearly met their death by the fumes of the sewer-gas. When rescued, the men were unconscious, and one of them remained in this state for nearly an hour; this is conclusive proof that very bad gas had formed in the sewer by the date named. The difficulty was to get rid of it, as flushing might aggravate the evil by driving the gases into the streets and houses. If the gases had been neutralised chemically no harm would have ensued, When the rain came it did the flushing with noteworthy results; it will be seen on reference to the chart that rain fell on ten successive days, from the 8th to the 18th July, and the sewage level would rise so that the bad gases which had been formed for twenty-two days were driven out and mixed with and vitiated the atmosphere. Within a few days after the discharge of this volume of sewer-gas an epidemic of typhoid occurred in the West End of London, and, on the 19th August, Lord Granby questioned the President of the Board of Trade as to the prevalence of typhoid in this district. The connection between the two phenomena is too direct to be lightly laid aside. It is maintained by the advocates of artificial ventilation that high shaft ventilation is a sanitary fallacy, as the tendency of a shaft is to check natural ventilation. This latter statement is of course readily admitted, the friction of the shaft having to be overcome, but the results of a series of tests made at Fulham and Sutton show moreover that during

FIG. 186A.—CHART SHOWING THE PRINCIPAL ATMOSPHERIC FORCES WHICH INFLUENCE THE FORMATION OF SEWER-GAS.



The firm lines and corresponding figures on left hand above datum show in grains per cubic foot how much heavier was the air in the sewers than that outside.

The firm lines and corresponding figures below datum show how much heavier was the air outside than that in the sewers.

The dotted lines and figures on right side show the rainfall in inches.

The wavy line and figures along the bottom show the average weekly temperature.

hot weather the ventilation is almost stagnant, and in the majority of cases the air was found to be coming out of the air-inlet gratings instead of the exhaust ventilators, and generally acting in an irregular and unreliable manner. Mr. W. Brown gives the details of these experiments in his paper on "The Sanitary Problem from the Sewer-gas Point of View" in *The Public Health Engineer* of December 24th, 1897. The following is a brief summary of the results :—

In the case of twenty-six street ventilators and twelve high shaft ventilators experimented with, the average amount of ventilation obtained from the former was found to be 43·85 cubic feet per minute (=263·1 feet per hour), and from each of the latter 4·25 cubic feet per minute (=255·0 cubic feet per hour). Now, where a grating giving 43 cubic feet per minute of ventilation is replaced by a shaft giving only 4¼ cubic feet per minute, there is clearly a very serious loss of ventilating capacity involved, the actual deficiency being as ten to one. But assuming—which of course is very far from being the case—that there is no practical difficulty in making the high shafts of equal ventilating area with the gratings, for which they are substituted, it was found that there would still be a deficiency of quite three to one against the high shafts ; for while the average ventilating power through one inch of ventilating area in a street level ventilator works out to 39½ cubic feet per hour, that through one inch of a high shaft amounts to only 13 cubic feet per hour. The further facts were also gathered that six out of the twelve shafts experimented with showed no movement whatever, and that on the only occasion on which the wind was registered "none," the high shaft in question showed more than twice the average of the high-shaft results. And now as to the "inlet and outlet" matter : fifteen of the "inlets" were found to be acting as "outlets," nine were "alternating out and in," and only two were acting as "inlets." In the case of the experiments at Sutton, where there is a newly laid down system of sewerage, involving all the latest improvements, in four tests, the current was going *in by the "outlet"* and *out by the "inlet"*; in two cases the current was alternating out, in, and dead; in the other two, the current was alternating out and in, and so on. It was noticed that the wind seems to have had little or no effect, thus showing that it is not a reliable force in sewer ventilation. During the summer months, when there is no movement of air into the sewer, and little or no rainfall (see chart), some ventilation may still be going on by the rise and fall of the sewage level, the rise displacing the sewer air, and the fall drawing in fresh air. Street level gratings under these circumstances produce natural ventilation to a considerable extent, but with high shafts it is different, for the amount of air displacement is often very much less than the cubic content of the high shafts, and consequently the rise and fall of the sewage level produces nothing more than an oscillation of sewer air up and down the shafts, that is to say, no natural ventilation, and consequently the development of dangerous gases in the sewers, which might not be developed, or not to such a dangerous extent, were the ventilators level with the street.

The following account of the experiments made when the Reeves system was first applied to the water of Leith intercepting sewer is taken from a paper read by Mr. Alex. Stewart, A.M.I.C.E., at the annual meeting at Edinburgh of the Association of Municipal and County Engineers, of which a report appears in *The Surveyor and Municipal and County Engineer*, of July 15, 1898. The views already advanced with regard to the difficulties involved in the ventilation of sewers are thereby strengthened and supported.

"When the Reeves apparatus was first started, numerous tests were made at the various manholes to determine the amount of air leaving or entering the sewer. These tests were made on the 30th and 31st May, 1898, and from the following Table it will be noticed that the results reveal a curious condition of ventilation :—

OBSERVATIONS AND READINGS OF THE VENTILATION OF THE SEWERS OF EDINBURGH AND LEITH ON MAY 30 AND 31, 1898.

Name of Street.	Inlet, feet per minute.	Outlet, feet per minute.	Weight of Air at Road Surface, grains per cubic foot.	Weight of Air in Sewer, grains per cubic foot.
London Street, East End	—	62	542·06	542·06
London Street, Cochrane Terrace ...	—	418	544·06	542·06
Mansfield Place	—	496	544·06	542·06
Comely Bank	—	186	551·36	545·53
Great King Street	—	837	536·16	542·06
Doune Terrace	—	3425	536·16	542·06
Moray Place	415	—	536·16	538·60
Nelson Street	—	739	532·84	536·33
Dundonald Street...	310	—	537·45	537·45
Great Stuart Street	—	1317	535·16	534·00
Randolph Crescent	310	—	535·16	539·75
Melville Street	—	992	535·16	538·66
Walker Street, opposite William Street	—	372	532·84	538·66
Walker Street	930	—	535·16	538·66
Chester Street	992	—	535·16	536·30
Rothesay Terrace	—	744	535·16	536·30
Palmerston Place	—	186	535·16	536·30
Eglinton Crescent...	—	372	535·16	532·80
Comely Bank (West)	186	—	551·36	545·53
Raeburn Place	737	—	546·89	545·53
Deanhaugh Street...	—	446	544·36	539·75
Ann Street...	—	1320	539·75	537·45

"The lowest record is in East London Street (east end), which showed 62 cubic feet per minute leaving grating; and the highest is from the grating in Doune Terrace, which registered an outlet of 3,425 feet per minute, pointing to the necessity for further ventilation of the adjoining sewer. At this time a slight smell was observed, which showed that the volume of gases was greater than the chemicals, as applied, were able to purify. Provision, however, has since been made to meet this extreme case also, as explained below. Undoubtedly the temperature of the trade refuse discharged into the sewers is one of the chief factors in producing this extraordinary movement of air. Some time ago experiments were made on the temperature of the trade refuse discharged into the sewers, and the highest temperature reached was 135° Fahr. When operations were being carried on in the intercepting sewer in James Place, Leith Links, which is 925 yards or thereby from mouth of outfall, on the 14th June, it was found that the temperature of the air in the sewer was as high as 75°, whilst that on the surface was only 60°. This shows the difficulties met with in dealing with sewer ventilation in a district where trade refuse is allowed to freely enter the sewers."

Sewer-gas as a disease producer, according to medical testimony, is a two-edged weapon. By mixing water and vitiating the air it lowers the human system and creates predisposition to disease therein, and by its action on food substances, including water, the multiplication of morbific germs takes place, which, entering the system, take advantage of its lowered condition, and thus the more readily produce disease.

Sewer-gas is not only a potent means of contamination, but it is also a very insidious one, and much of the mystery as to the cause of disease, and many seeming inconsistencies in connection with disease, in its epidemic form especially, will, it is believed, disappear when the matter is viewed from the sewer-gas standpoint.

Considerable attention has been applied to the chemical treatment of sewage at the outfall, but the sanitary advantage to the town itself of such treatment is absolutely *nil*. Mr. Harris Reeves, however, proposes to begin reform in the street sewers, and the following is a brief description of the method he advocates :—

Two chemical-ware vessels are placed in a recess formed in a manhole (Plate XVIIIA), and one of the vessels is filled with strong sulphuric acid and the other a specially prepared mixture of dry manganate of soda. The manganate of soda chamber is connected with a water supply, and the cock is so regulated that a small stream of water washes through the manganate, the solution escaping on to a porcelain capsule or splash plate below the apparatus ; on to this splash plate the sulphuric acid is run so as to mix continuously with the solution of manganate. The action of the strong acid is to convert the cheap manganate of soda into the permanganate, and by the heat set up to evolve vapours of permanganic acid, probably one of the most powerful deodorants in existence (Dibdin). A strong disinfecting liquid at the same time enters the sewer.

A drop stop-valve is fixed to the water pipe where it enters the manhole, so as to close the pipe when the pressure in the main ceases and prevent air being sucked into the main. There is also another valve and a syphon of water, about three feet deep, which completely locks the pipes against any back pressure. A branch pipe with valve and spray is fitted beyond the syphon and the discharge from the spray is directed on to the three pots on which the chemicals fall after the gases are given off. The result of the water striking against the pots is that a fine spray or mist of the chemicals is produced which, in falling into the sewer, purifies the gases coming up the shaft.

The system is said to work with very satisfactory results, and has been adopted at Sutton, Epsom, Fulham, Eastbourne, Ilford, Edinburgh, and other places.

The cost of one set of apparatus varies from £10 upwards, according to size and the work required to be done.

At Edinburgh the cost of altering the manholes to suit the apparatus was £7 each.

When the whole sewerage system of a town is worked on the Reeves plan it would require from two to four apparatuses per one thousand inhabitants, according as the town was residential or manufacturing, and the annual cost per annum per apparatus would average about £2 3*s*.

The apparatus and chemicals are supplied by Reeves Chemical Sanitation, Limited, 17, Victoria Street, Westminster.

SEWER VENTILATION BY THE REEVES SYSTEM.

Sections of Manholes showing Arrangement of Apparatus.

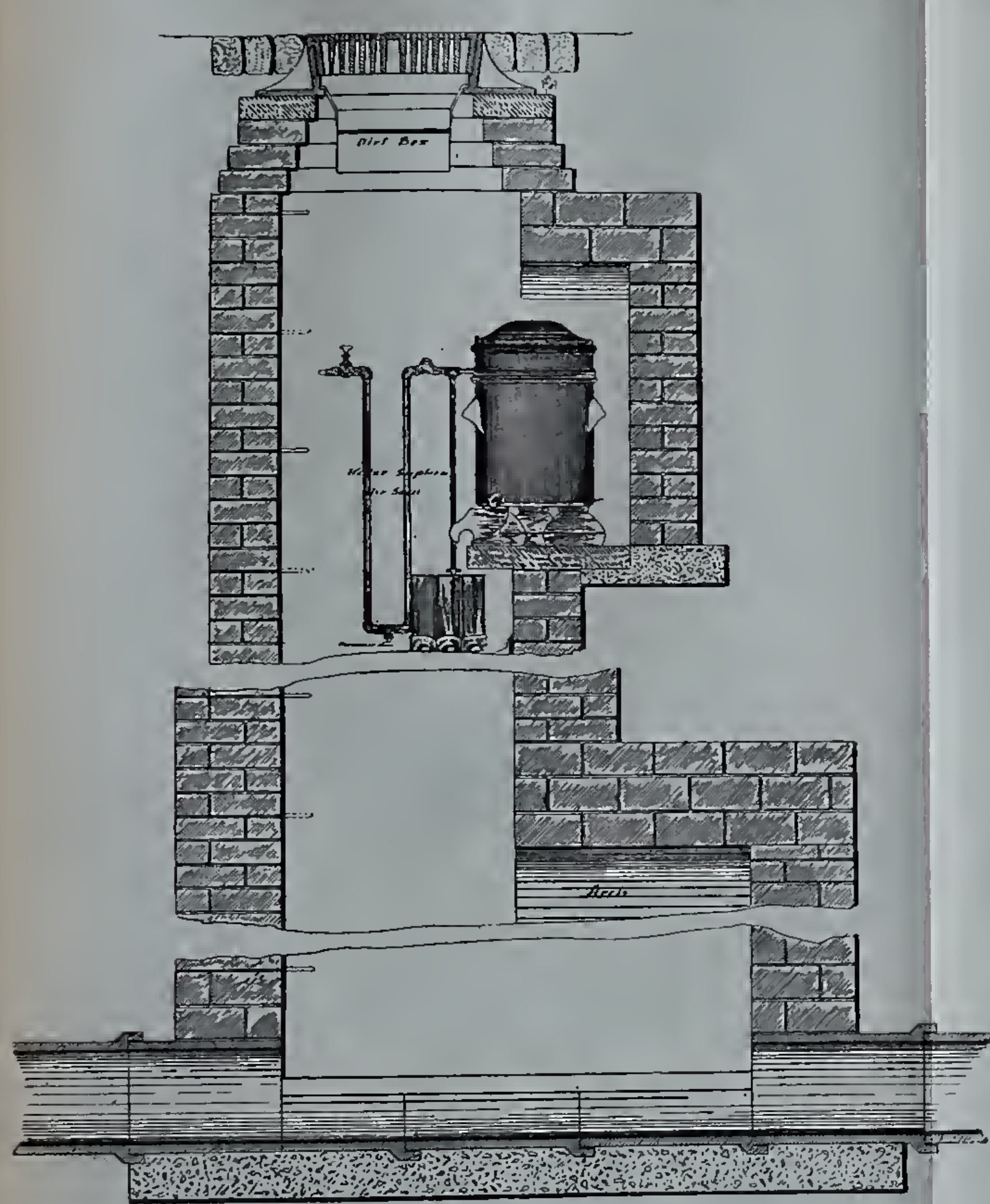


Fig. 1.

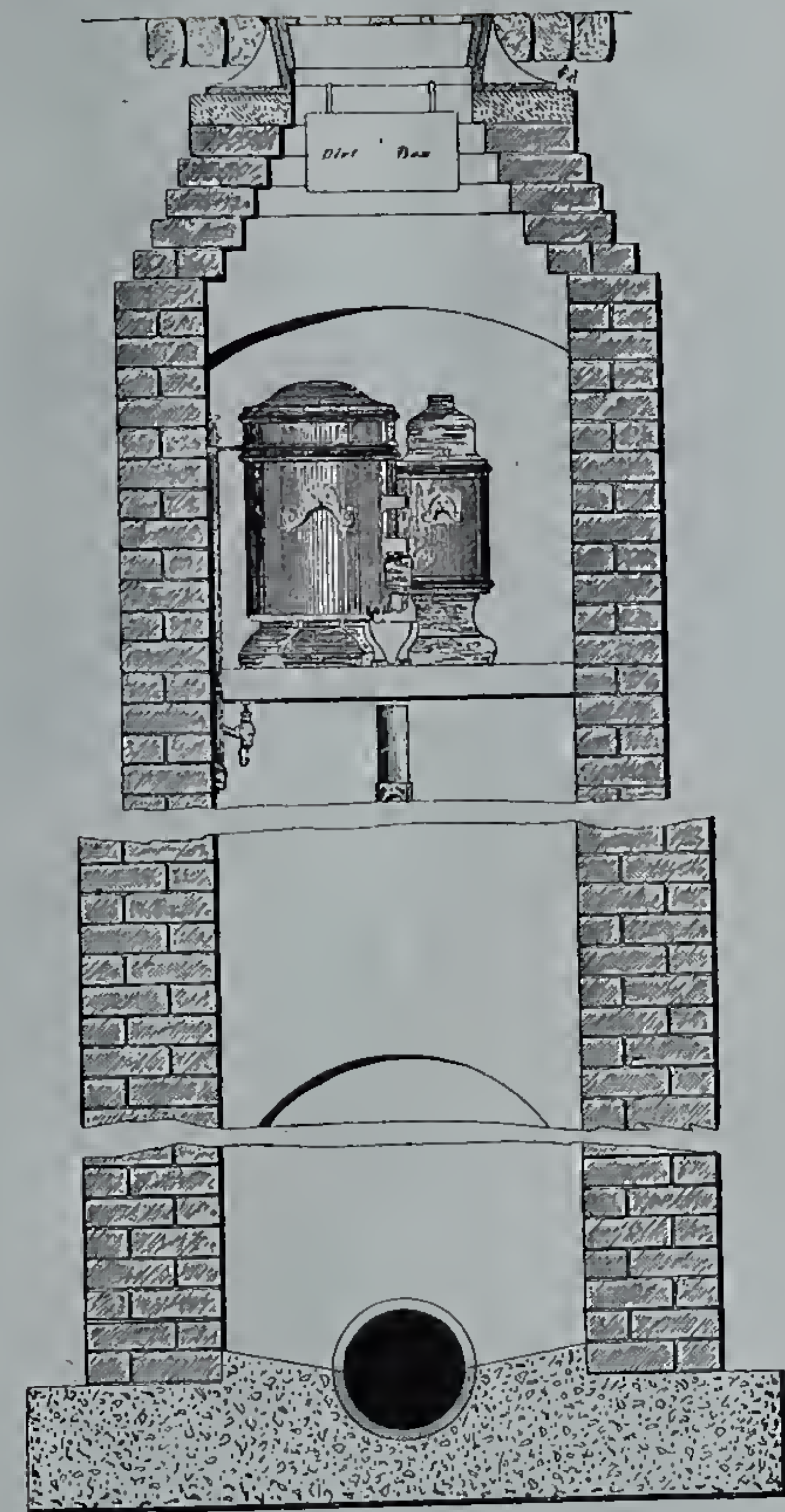


Fig. 2.

To face page 288F.

CHAPTER VIII.

TRAPS.

Object of Traps.—Traps are used in connection with foul water drains, to prevent the passage of sewer-gas in a particular direction through a pipe, or through the apparatus of a w.c. or latrine, or, in fact, wherever its presence would be obnoxious or injurious.

They should be, like the sewers, self-cleansing, *i.e.*, they should be made so as to allow the free passage of the liquid sewage as well as the more solid portions contained in it. Consequently the traps should not be rectangular either in longitudinal or transverse section, as any sudden changes of shape tend to produce deposit, which is most objectionable and insanitary.

Water-lock.—Traps are constructed so as to establish a water-lock, through which water, even though carrying solid matter, can pass freely.

The depth of water-lock or seal varies from half an inch to three and a half inches, depending on the nature and position of the trap.

Failure of.—The water-lock of any form of traps, however, cannot be relied on, as it may fail in many ways:—

1. By pressure of gases forcing the foul air through the water.
2. By a partial vacuum being caused by the pipes being emptied suddenly, and so drawing off the water by suction or syphonage from the trap.
3. By the evaporation of the water, lowering its level below the tongue of the trap.
4. By syphonage, such as may be caused by a piece of rag or paper lying partly in the trap with its end hanging down through the outlet.
5. By sewer-gases being absorbed at the surface of the water at one side of the trap, and being given off on the other side.

Traps: Necessary Evils.—Consequently, traps should be regarded as necessary evils, and their use should be avoided as much as possible by reducing their number to a minimum, and for this reason the only connection with a foul water drain admissible within a building is the one necessary for a water-closet; in no other case should the drain be allowed to enter the house.

By the absolutely separate system, the only gully traps required are in connection with sinks, and thus the danger of any of them running dry is minimized, and constant supervision to obviate this risk rendered unnecessary.

Position of.—In arranging for the position of the traps, care must be taken not to interfere in any way with the ventilation of the sewer or drains.

Good Flush Necessary.—A good flush of water should always be provided in connection with every trap, and special flushing chambers have often to be supplied.

Form of.—The form of the traps, or gully, should always be adapted to the purpose for which it is intended.

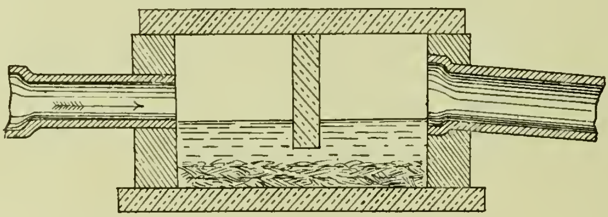


Fig. 217.—Mason's Trap.

Mason's Traps.—Sometimes Mason's or Dipstone traps (Fig. 217) are found in old sewers; they are worse than useless, as the junction between the dipstone and the cover is seldom gas-tight, so that sewer-gas is emitted. In addition to which a deposit takes place in them, which is stirred up with each discharge, the cure being thus worse than the disease; sewage retained in this manner and allowed to putrefy being infinitely more dangerous than fresh sewage. Traps which retain solids are of use for special purposes, such as preventing road detritus, etc., from entering a foul-water drain; comparatively few would be required with the partially separate system, and none with the separate system. They will be treated of under the head of surface drainage.

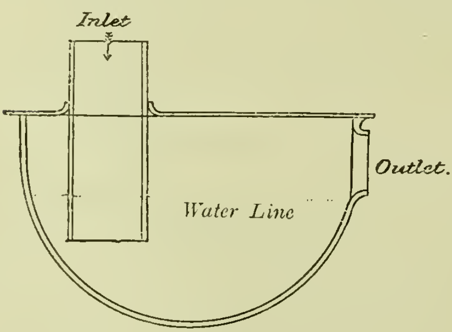


Fig. 218.—Old Pattern D Trap.

D Trap.—The old pattern D trap (Fig. 218) was made of lead, and at one time was much used in connection with fitting w.c. basins in houses. It was a most dangerous arrangement, and being rectangular in section, it is not self-cleansing, and should never be used.

Self-cleansing Traps.—Traps are made in a great variety of forms; as already mentioned, those which are self-cleansing, such as syphons (Figs. 219—221), which allow all solids to be carried into them, and to be swept through them easily by the flow of water, should alone be used for sewage; the first three descriptions are commonly used for fitting w.c. basins, and the last on a line of drains.

As the sectional area of a syphon trap, even of the smallest size made in stoneware (three inches, Fig. 234, page 278), is large in proportion to the amount of the liquid discharged from a sink, there is a tendency for filth to accumulate in it, so that everything should be done to increase the velocity of discharge through it as much as possible. In order to effect this in the case of a rectangular connection, a drop should invariably

Fig. 219.

Fig. 220.

Fig. 221.

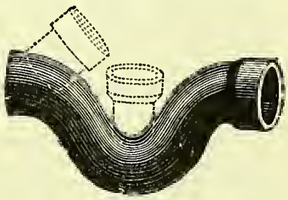


Fig. 222.

be given of at least three inches from the invert of the pipe to the surface of the standing water in the trap, as shown at D in Fig. 223, and also in Figs. 224—226. In this way a cascade action is insured, which helps to overcome the resistance in the trap. The drop in Figs. 227 and 228 is six inches. In addition to the foregoing, in order to still further increase the self-cleansing action of the trap, it is recommended, except in the case of a 4-inch pipe, to use one of smaller sectional area than the pipe discharging into it; thus for 6, 9, and 12-inch pipes, 4, 6, and 9-inch traps might advantageously be used.

Examining Eyes are desirable for clearing traps or the drain beyond when required; the latter are also available for ventilating purposes.

An examination eye over a bend in a syphon is objectionable, as it checks the flow.

Special Forms.—Several special forms of traps by Buchan, Weaver, and Hellyer, are shown in Figs. 223—234, and also special connections for soil-pipes, fresh air inlets, etc., for Hellyer's trap, which can thus be adapted to any particular case. Figs. 223—232 are ventilating intercepting traps; the trap shown in Fig. 233 is intended to be used in

Stoneware Traps.

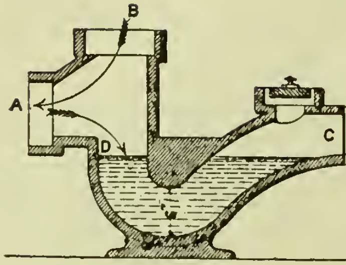


Fig. 223.—Buchan's Trap.

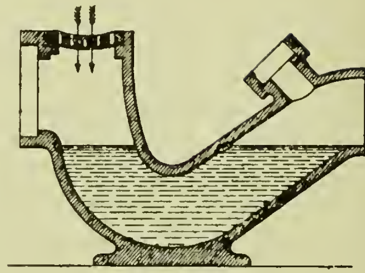


Fig. 224.—Weaver's Trap.

Hellyer's Traps.

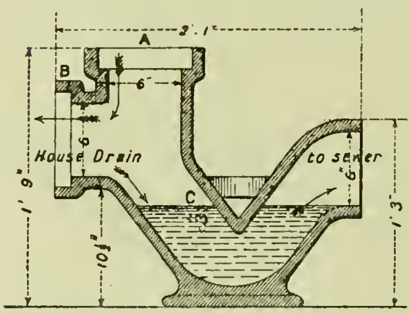


Fig. 225.—"Pipe-Shaft" Trap in one piece with small Weir Drop.

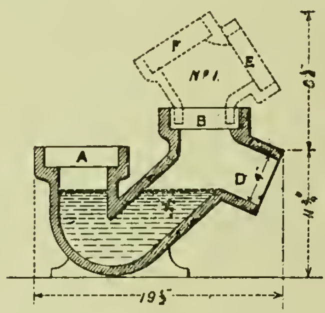


Fig. 226.—Disconnecting Trap without connection.

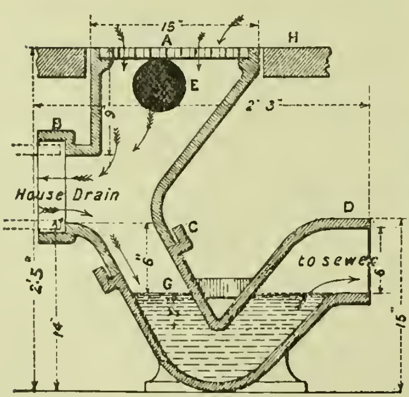


Fig. 227.—Section showing the size of a 6-inch Syphon.

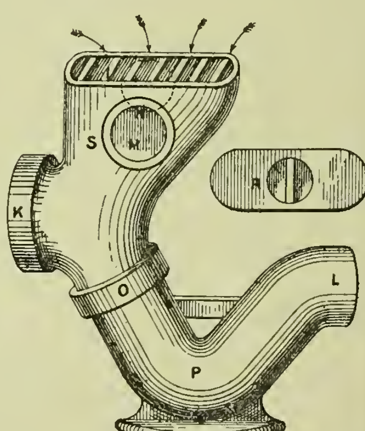


Fig. 228.—View of a 6-inch Ventilating Drain Syphon and Sewer Interceptor.

connection with two 4-inch drain pipes and a vertical soil-pipe, though one of the junctions may be used for ventilating purposes, and the small trap in Fig. 234 is for use as a gully for reception of foul water from baths or sinks. In addition to these, there is a great variety of patterns of traps made by different makers, such as Finch & Co., Winser & Co., Crapper, Duckett, Nicholls & Clarke, Stone & Co., etc.

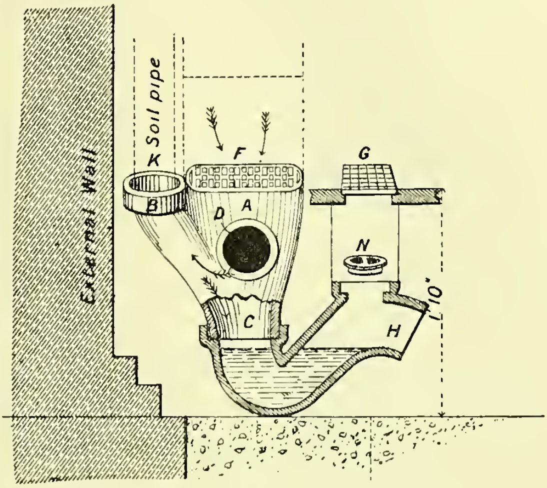


Fig. 229.—Ventilating Intercepting Trap.

Buchan's Patent Trap.—Fig. 223 is Mr. W. P. Buchan's "Patent Trap," made by Messrs. J. & W. Craig. It is intended to act as a ventilating inlet to a soil-pipe, and has a drop of three inches from the bottom of the pipe to the surface of the water in the trap. Its air inlet is only six inches diameter, same as Doulton's. The outlet C is four inches diameter. This should be made six inches for a 6-inch drain. The dip, or water seal, of one and a half inches is too little, as the current of air for ventilation constantly passing over the exposed surface of the water in the well of the trap induces evaporation, so that, if not frequently used, the trap soon becomes unsealed.

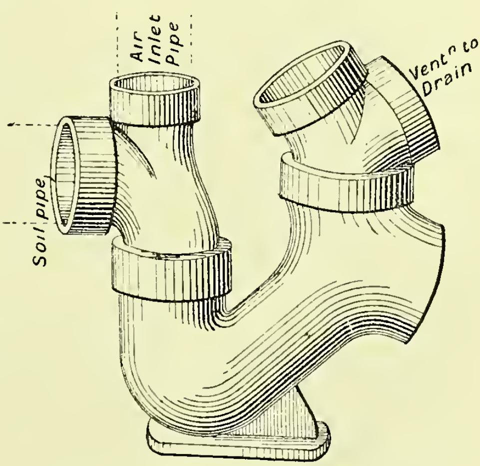


Fig. 230.—Ventilating Intercepting Trap.

Weaver's Trap is shown in Fig. 224. It is a ventilating trap, and is provided with a cleansing eye in such a position as to enable cleaning rods to be passed into the drain.

Hellyer's.—Figs. 227, 228, represent a trap by Mr. S. S. Hellyer, which he calls a "Ventilating Drain Syphon and Sewer Interceptor." Its air

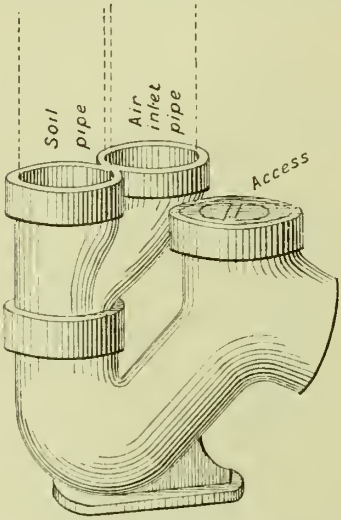


FIG. 231.—Ventilating Intercepting Trap.

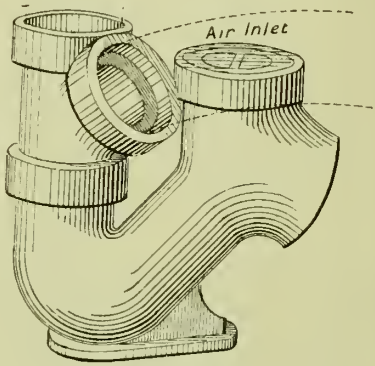


FIG. 232.—Ventilating Intercepting Trap.

inlet is of considerable dimensions in one direction—that shown in the section — but crosswise it is reduced to the width of the pipe. The trap in the part marked D is of smaller size than the drain itself, being, for a 6-inch drain, four inches diameter, thus preventing any sediment forming in the trap, and also insuring the entire renewal of the water in the trap more frequently than it is in traps which are of the same size in the throat as elsewhere. There is a vertical drop of six inches from the bottom of the house drain to the level of the standing water in the trap.

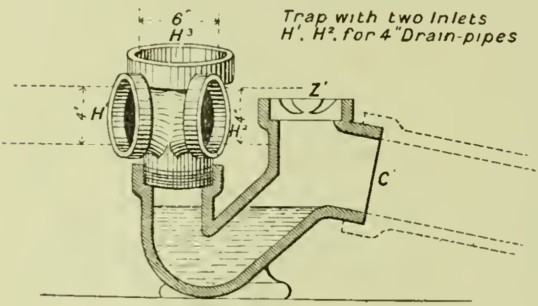


FIG. 233.

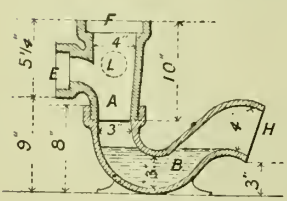


FIG. 234.—Intercepting Trap for Sinks and Baths.

Doulton's Improved Sewer-gas Interceptor.—Fig. 235 is Doulton & Co.'s "Improved Sewer-gas Interceptor." The inlet socket A, as drawn, is intended to receive a drain-pipe, six inches internal diameter, the air inlet B being of the same diameter. It should be larger, and the manufacturers can easily make it so. In this case it should be enlarged to twelve inches, or at least to nine inches diameter in the clear. The air outlet C is six inches diameter, as it ought to be for a 6-inch drain.

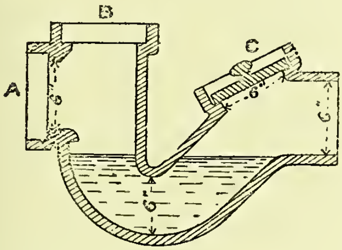


Fig. 235.—Doulton's Sewer-gas Interceptor.

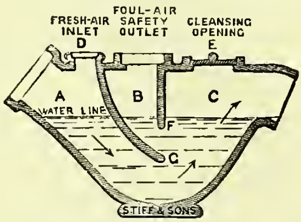


Fig. 236.—Stiff's Interceptor Sewer Trap.

It is closed with an earthenware stopper, put in with common mortar, not cement, so that when it is necessary to remove it, it can be done without breaking the socket of the pipe, as common mortar does not set hard in damp ground, while it keeps the stopper sufficiently air-tight as long as it is required to remain there.

Stiff's Interceptor Sewer Trap.—A section of this trap is given in Fig. 236. It is claimed that by the use of this trap the entrance of sewer-

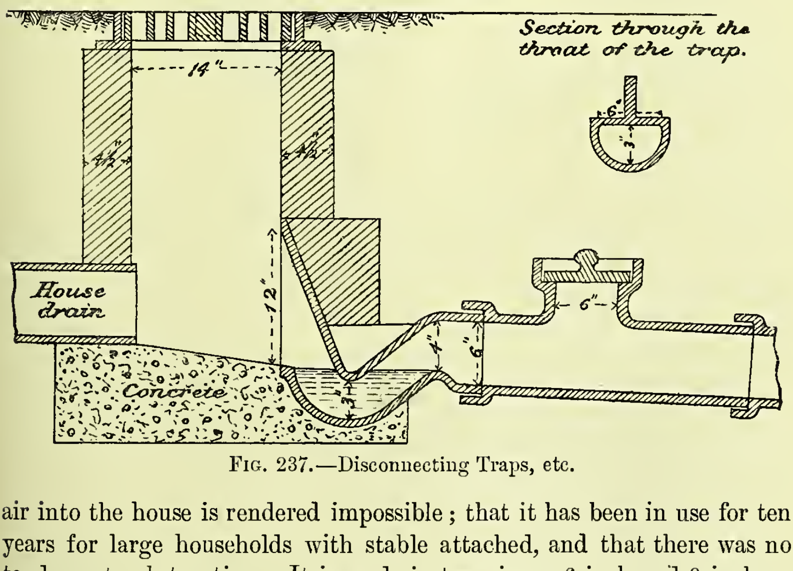


Fig. 237.—Disconnecting Traps, etc.

air into the house is rendered impossible; that it has been in use for ten years for large households with stable attached, and that there was no tendency to obstruction. It is made in two sizes—6-inch and 9-inch.

Ingham & Sons'.—Fig. 237 is Messrs. William Ingham & Sons' quick-motion trap, which is intended for use in connection with a small masonry pit. It is claimed for this trap that the obstruction to the flow of sewage through it is less than in other traps, inasmuch as there is no unnecessary and useless sinking of the sides of the orifice below the water-level. The top of the trap, cross-wise, is straight and horizontal, parallel with the surface of the water in the trap. Its dip is, therefore, fully effective the whole width of the drain-pipe, whilst in all-round sections both sides dip uselessly into the water and offer unnecessary obstruction to the flow of sewage. Those who have had experience of these traps regard them with favour, and when we examine the principles on which they are constructed there appears every reason why that should be so. The trap effectually bars the passage of air; its dip is the same as that of other traps, about two or two and a half

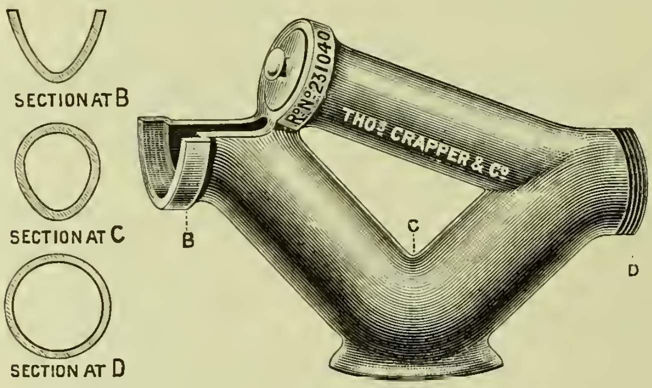


Fig. 238.—The "Kenon" Disconnecting Trap.

inches, and this is effectively disposed, while the bottom of the trap is not sunk more than five or five and a half inches below the bottom of the drain, instead of eight or eight and a half inches. The body of water in the trap being small, is frequently entirely renewed. The outlet is on the next adjoining pipe, not on the trap itself. It is one of the points of this trap that when the sewage leaves it, it falls immediately and freely over the lip into the pipe, and acquires motion thereby to start with, and a free outlet in the trap is maintained.

The circular bore is, however, by some considered the best for syphons intended to be self-cleansing, and their internal diameter should certainly not exceed that of the pipe running into them, and might be less, as already mentioned.

The "Kenon" Disconnecting or Intercepting Trap.—This trap (Fig. 238) is manufactured by Messrs. Crapper & Co. It has a deep seal, and the cross section varies, with the object of increasing the flushing power. It has been very extensively used in drainage works.

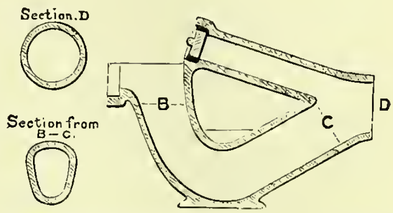


Fig. 239.—Quick Flush Trap (Light's Patent).

Quick Flush Trap, Light's Patent.—This trap (Fig. 239) is so constructed that, while having a deep water seal, it offers the least possible resistance to the passage of the contents into the drain. It is stated that the egg-shaped form from B to C greatly increases the flush at the point where the drain is most likely to become obstructed. It is made in three sizes—viz., four, six and nine inches in diameter—by Messrs. Stiff & Sons.

A Sewer-gas Interceptor, fitted with Sykes' air-tight screw stopper to examining eye, is shown in Fig. 240. It is made by the Albion Clay Co., Ltd.

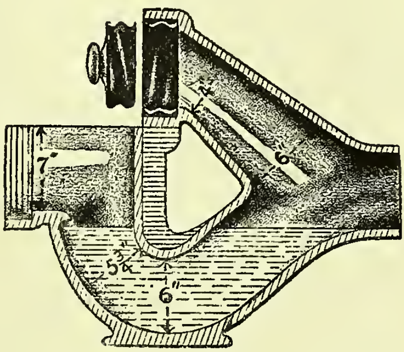


Fig. 240.—Sewer-gas Interceptor, fitted with Sykes' Air-tight Screw Stopper.

Main Intercepting "Loco" Trap.—The use of this trap in a manhole or disconnecting-pit is shown in Fig. 241. It is supplied by Mr. F. C. Lynde, C.E.

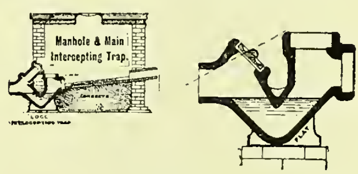


Fig. 241.—Main Intercepting "Loco" Trap.

Sykes' Patent Interceptor (Fig. 242).—This trap obviates the necessity for an air-tight cover to the manhole. It has all the advantages of a self-cleansing trap, and affords ample means of access both for inspecting and rodding the drains. It is provided with an attachment for a sewer ventilator, which need not be used unless it is intended to attach a pipe at this point for that purpose, as all these openings are provided

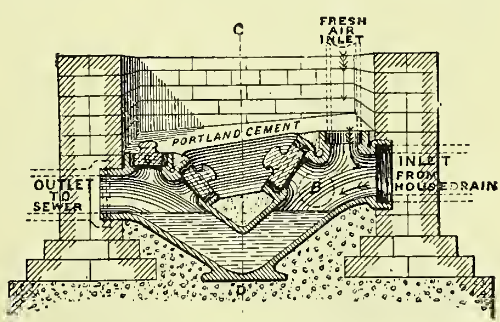


Fig. 242.—Sykes' Patent Interceptor.

with air-tight screw plugs. There is also a connection for the fresh-air inlet to the house drain, so that an absolutely air-tight manhole cover is not necessary, and the usual "open channel" can be dispensed with.

Cast-iron Disconnecting Trap (Dent & Hellyer).—This trap (Fig. 243) is made for connecting to *cast-iron* drain-pipe, and admits of the joints being caulked with lead. The trap is five inches in diameter, and is provided with a connector (B) for a 5-inch cast-iron drain, and socket-head (F) for a 5-inch inspection shaft and fresh-air induct. An oval-shaped doorway is formed at *h*, to pass a "drain stopper" through for fixing in the mouth of the trap at E, to test the drain with water. When the drain is of larger size than the trap, cast-iron taper pieces can be used, six inches to five inches on the inlet side, and five inches to six inches on the outlet (K). By using a branch connector, and fixing

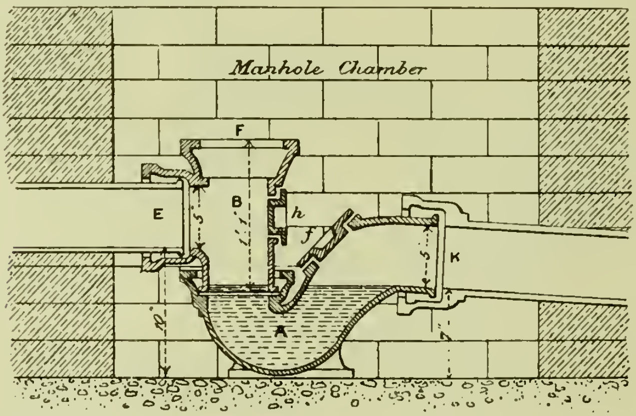


Fig. 243.—Five-inch Cast-iron Trap, with turn-round Inlet, and Head for Pipe-shaft.

same one upon the other, two or three drains may be made to discharge into one trap-shaft, provided that the falls admit of it. Fresh air may be admitted through a grating fixed over the pipe-shaft; or the top may be sealed down by a cover-plate, and fresh air brought into the shaft by a branch from the most convenient place, with a mica valve fixed in the mouth of it. This trap could be made to stand in a brick-built manhole chamber, and as all the joints would be made with metallic lead, there would be no risk of unsoundness in the drain or its joints.

"Loco" Deflecting Traps.—The principle of deflection is also applied by Mr. Lynde to traps for the purpose of causing them to be self-cleansing. The bottoms of the traps are flattened deflecting surfaces, and cause the water to flow with great rapidity through them. All "Loco" traps have fully two and a half inches drip, and only contain sufficient water to ensure an effective trap, thus avoiding the foul accumulation which so often occurs in other kinds. "Loco" traps with vertical outlets are shown in Figs. 244—246, and are preferred by Mr. Lynde for general work, and to be fixed in connection with a deflector bend, as shown in Fig. 247, thus ensuring a high initial velocity. Similar traps, but with horizontal outlets, are shown in Figs. 248—250.

VERTICAL OUTLETS.

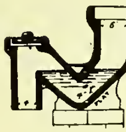


Fig. 244.

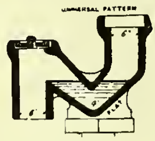


Fig. 245.

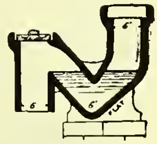


Fig. 246.

Mooney's Self-cleansing Gully and Block are shown in Fig. 251. It is claimed that the block not only prevents the passage of foul gas up the waste pipes, but also avoids splashing and running over ; the grid is so made as not to cause any filthy deposits to remain around it. The trap is made with a square base, so as not to sink or slip when in position, and is stated to be self-cleansing, and that it will resist pollution and evaporation longer than any gully trap in the market, as the water surface exposed to the atmosphere and sewer-gas is small.

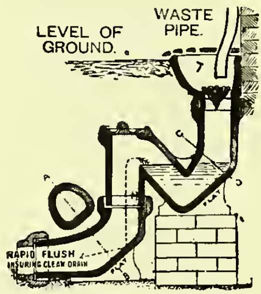


Fig. 247.—"Loco" Deflector Bend, with Trap.

HORIZONTAL OUTLETS.

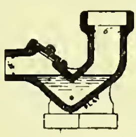


Fig. 248.

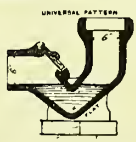


Fig. 249.

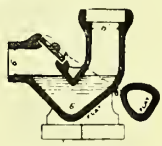


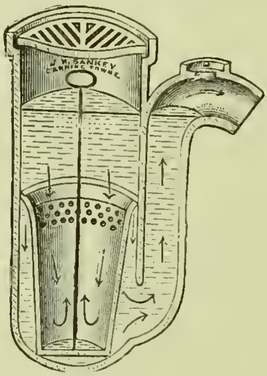
Fig. 250.

Sankey's (Patent) Deep Intercepting Gully.—The following description is taken from *Invention*, January 19th, 1895 :

"A deep intercepting gully of a simple and ingenious type has been introduced by Mr. J. H. Sankey. It is intended for use in house drains, yards, stables, factories, gardens, schools, hospitals, streets, parks, etc., and amongst the chief advantages claimed for it are, that it is compactly constructed in superior vitreous stoneware, which is well glazed and practically indestructible, and that its use renders the escape of sewer-gas or the blocking up of the drain with

Fig. 251.—Mooney's Self-cleansing Gully and Block.

mud or grease impossible. The depth of the gully, of which a sectional view is given in Fig. 252, is designed to make the trapping much more effective than usual. The position of the outlet appears to ensure an efficient water seal, even in the driest weather, and thus prevents any escape of gas, and a specially constructed perforated bucket with a lip intercepts and catches all foreign matter, such as stones, grease, mud, etc.,



Section.

FIG. 252.—Sankey's Intercepting Gully.

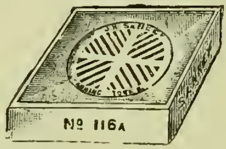


FIG. 253.—Stoneware Kerb.

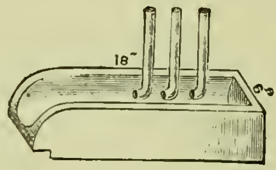


FIG. 254.—Special Channel.

and can easily be removed, emptied and replaced, as often as necessary, by means of a handle on a rod fastened to the bottom of it.

" For the larger gullies used in streets, tipping buckets can be supplied, and these, when used in conjunction with a small hand crane attached to the back of the mud cart, can be emptied direct into the latter, thus saving considerable labour as well as the public nuisance created by ladling the filth out and depositing it in the road, as conducted with existing gullies. Special kerbs, gratings, and frames are supplied to fit this gully, and for school playgrounds, etc., locking grates can be furnished. These kerbs, which we illustrate in Fig. 253, are also made of glazed vitreous stoneware, with grids of the same material or of iron. A collar or rim round the kerb fits flush into the socket of the gully, and thus prevents any back drip.

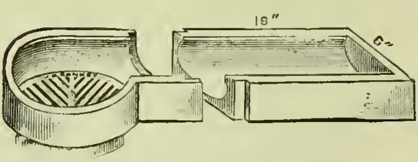


FIG. 255.—Special Channel and Kerb combined.

" For receiving waste water from the house a special channel (Fig. 254) can be used with the kerb, and, having an overhanging lip or side, we understand, it prevents splashing, and also meets the requirements of the various Boards of Works.

" Fig. 255 shows an improved type of channel and kerb combined. It is made in two pieces, which can be easily joined, and it also has the overhanging sides to prevent splashing, as shown in Fig. 256, which is a sectional view of this channel and the one illustrated in Fig. 254.

"The iron grating and frame, shown in Fig. 257, is strongly made, and intended for use when the gully is required in stable yards, in streets, or anywhere else where there is heavy traffic. This, likewise, has a collar on the rim underneath, which fits flush into the gully to prevent any back drip.

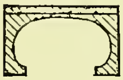


Fig. 256.—Section of Figs. 254 and 255.

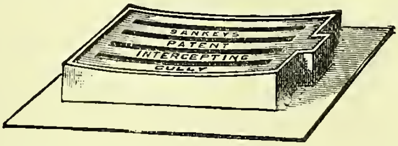


Fig. 257.—Special Iron Grating and Frame.

"The gullies are formed, as we have intimated, in various sizes and for all purposes, and we are informed that builders and architects, by whom they have been adopted, have expressed much satisfaction with them."

Grease Traps.—The pipes from sinks should discharge in the open over the gratings of the gullies, but sometimes when the refuse on the surface would be too unsightly, the connection is made below the surface.

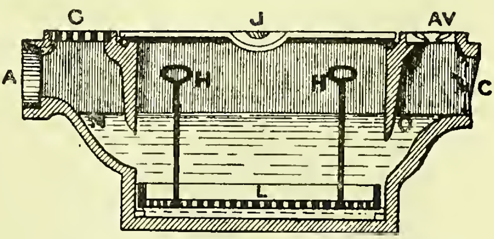


Fig. 258.—Hellyer's Grease Intercepting Tank.

Grease traps are intended to arrest fatty matter from scullery sinks, and thus prevent its choking the drain. Grease, when in solution with hot water, escapes through the finest grating of the sink waste, and gets away into the drain, where it congeals, and becomes a nuisance. It is, therefore, essential to have special traps, with a grease-collecting chamber of considerable capacity, proportional to the amount of sink water to be passed through it, so as to prevent the displacement of the body of water in the trap too rapidly, in order to ensure the grease being chilled and deposited in it. The trap should be easily accessible, for periodical cleaning. A non-conducting material is preferable for the construction of these traps.

Hellyer's.—Hellyer's patent grease intercepting tank or trap (Fig. 258) has been widely adopted. There is plenty of room for cleaning purposes, and a tray is provided to remove the fat. There is no ventilation for the grease-collecting chamber, and it would apparently be advantageous to add a contrivance for this purpose, in connection with the recommended drain ventilation.

The Patent "Loco" Grease Box.—The object of this apparatus (Fig. 259) is to eliminate the grease from scullery waste water, and soap from wash-house water, so that it will be prevented from passing into and choking drains. The hot, greasy water comes in contact with the large body of cold water in the removable iron box, and the grease contained in it is solidified by the reduction in temperature, and floats on the surface within the iron box. The water, thus freed from grease, passes down the drain through the trap, in the direction shown by the arrows. A current of fresh air is maintained within the grease box by two 3-inch diameter ventilating-pipes, on the upper end of one of which an extract ventilator is generally fixed. Rust-chambers are placed at the lower ends of the ventilating-pipes, if of cast-iron, to prevent the bends from becoming choked. The grease should be removed about once a week.

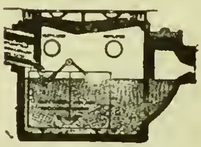


Fig. 259.—"Loco" Grease Box.

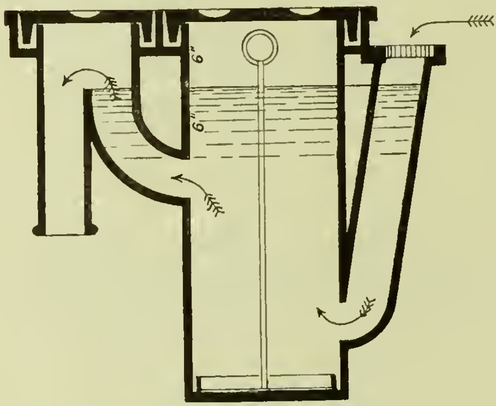
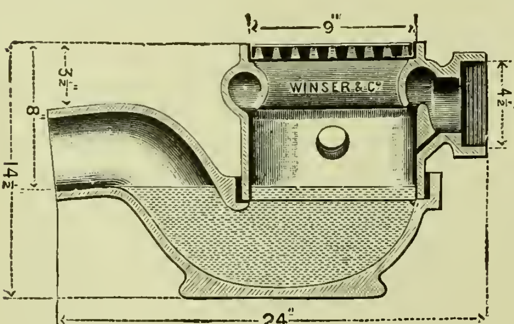


Fig. 260.—Colonel Moore's Improved Grease Trap.

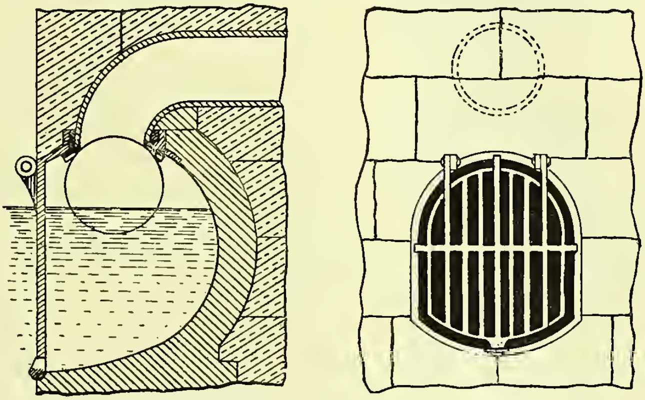
Author's Pattern.—An improved grease trap by the author is shown in Fig. 260. The main current passes through the body of the water, thus allowing the lighter portions to float on top, whilst the heavy sink to the bottom. The trap is provided with a strainer, which can be readily removed, carrying with it the whole of the accumu-



Section.

Fig. 261.—Winser's Flushing-Rim Grease Trap.

lation in the body of the grease traps. The inlet arm reaches to within a few inches of the bottom, and the outlet is six inches below the water level. The outlet overflows over a bridge into the drain, and is provided with an air-tight cover. This trap gives great satisfaction, and made



FIGS. 262, 263.—Self-closing Traps or Valves.

in iron, and glazed on the inside, must be very durable. Every part can be got at and cleaned. It may be obtained from Messrs. Shanks & Co.

Winser's Flushing-Rim Grease Trap is shown in Fig. 261. It is claimed by this arrangement that the interior of the trap is kept clean, and any position can be readily got at when required.

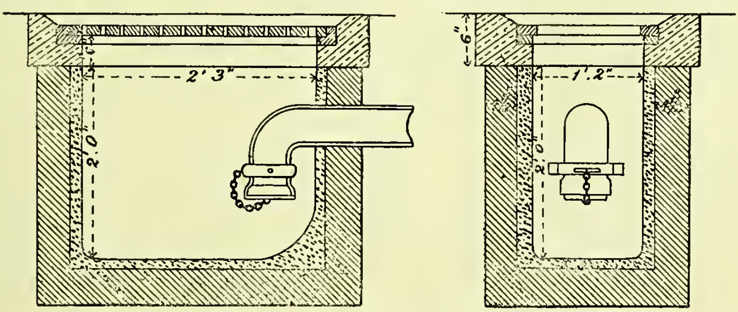


FIG. 264.—Catchpit for Stable Yards.

Self-closing Traps.—In some cases, as an extra precaution, drains are closed against sewer-gas by means of self-closing traps, or valves, which are opened by the flow of sewage. They are often necessary in connection with outfalls, to prevent gases being forced up the drain by a rising tide. Sometimes, instead of a hinged flap, a ball is used, as in the figure. Means of examination should always be provided. The one shown in Figs. 262, 263, is made by G. Jennings.

Gullies for Stables.—Gullies for stable drains should have a grating attached to the inlet to the drain, and turned downwards, as shown in Fig. 264, in order to prevent floating straw, etc., getting into the drain. They require to be frequently cleared out.

There is always an accumulation of filth in these catchpits, which is dangerous, especially in hot climates, and the one shown in Fig. 265 has

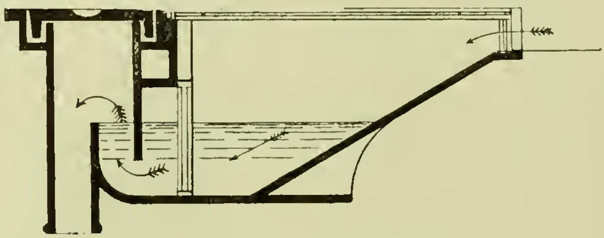


Fig. 265.—Colonel Moore's Stable Trap.

been designed by the author to meet the requirements of the case, and has met with marked success in Bermuda.

The solid matter is kept as far as possible from entering the catchpit by means of a surface gutter with a small siding or shunt on it. The manure and straw is thus left behind in the siding by the ordinary operation of brushing down, and the grooms soon find it to their advantage not to sweep the solids into the catch-pit, as it chokes the gratings and prevents the liquid from running away. The catchpit is small and easily cleaned out. A bucket of water thrown in after use makes it sweet and wholesome. It may be procured from Shanks & Co.

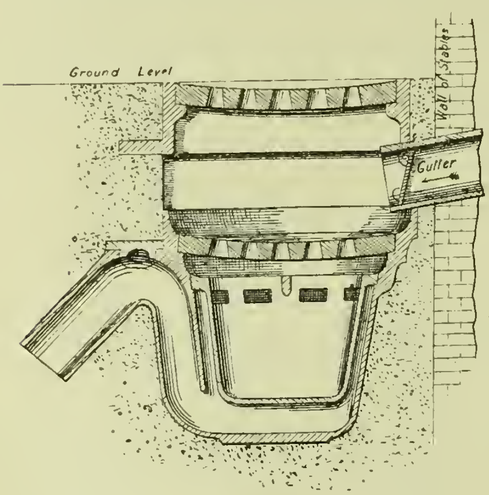


Fig. 266.—Cottam and Willmore's Stable Gully.

Cottam and Willmore's Sanitary Gully.—This gully (Fig. 266) is designed for use in large stables in connection with the "Claremont" gutter, and admits of the latter running as much as ten to twelve inches deep (where it leaves the stable). The silt pot can be removed when required without breaking the seal of the trap. The gutter is carried through the wall of a smaller size than is used in the stables, with a solid cover, and discharges into a brick pit just above the gully, a separate grating and frame being provided at the yard levels. The gully is supplied by Messrs. Hayward Brothers & Eckstein.

Broad's Stable Gully is shown in Fig. 267. It contains a perforated bucket, which intercepts particles of straw, etc., which have passed through the grating, and are likely to choke the drains. It is provided with a heavy iron frame and grating for stable use, and is made with either an S or P outlet as required. It is supplied by Joseph Cliff & Sons.

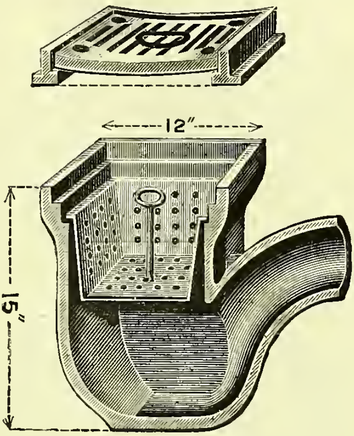
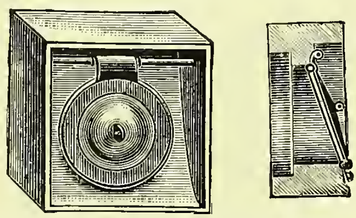


Fig. 267.—Broad's Stable Gully.

Flaps.—These are sometimes fixed over the outlets of house drains with the object of checking the back-flow of sewage in time of flood, etc.; but they often fail in consequence of obstructions to their closing being left on the seating. A flap of this nature, supplied by Messrs. Cliff & Sons, is shown in Figs. 268 and 269.



Figs. 268, 269.—Flaps for checking Back-flow of Sewage.

Ball Tide Valve.—These valves act better than flaps. The ball hangs clear of the sewage flow, but is carried up by the rise of the sewage level against the seating. Fig. 270 is a valve of this nature by Couzens, for flooded cellars. It should be fixed as near the sewer as possible, and in an accessible position. The ball is made of copper, and the seating is formed with india-rubber. This trap may be obtained either from G. & F. Couzens, or of Henry Dennis, manufacturer, Ruabon. Appliances of these descriptions should only be used where absolutely necessary.

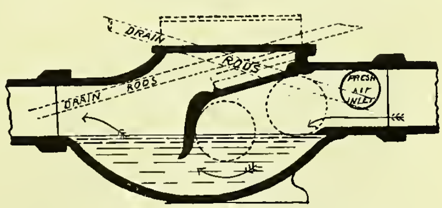
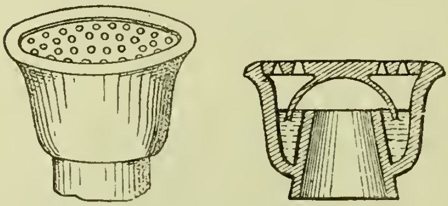


Fig. 270.—Ball Trap Interceptor (Couzens' Patent).

Traps for Sinks.—All sinks, even now that they are invariably cut off from direct communication with the drain, should always be provided with a trap immediately below the basin, or trough, to prevent the smell emitted by the matter deposited in the interior of the pipe entering the house ; *vide* Figs. 271—275.

Bell Trap.—The old-fashioned bell trap (Figs. 271, 272), though constantly met with in use in sinks, and sometimes for gullies, etc., is a very defective trap, because, 1st, it is unsealed whenever the perforated bell cover is removed ; 2nd, the water soon evaporates from the shallow cup, and the trap is unsealed ; 3rd, the bell, being only attached to the perforated plate at the apex, is easily broken off and lost, especially when only riveted on. The loss is not apparent when the plate is in its place, and thus the sewer-gases are allowed to pass unhindered.



Figs. 271 and 272.—Bell Trap.

Jennings' Bell Trap.—A better form of bell trap is shown in Fig. 273, as made by Jennings and other makers. The shallowness of the cup in all these traps renders them liable to become untrapped by evaporation, and the trap itself soon gets clogged with grease. It is very difficult to cleanse it, so that this description of trap should never be used.

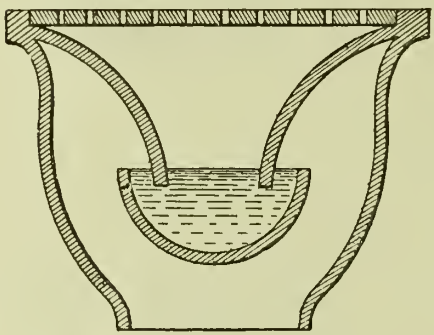


Fig. 273.—Jennings Bell Trap.

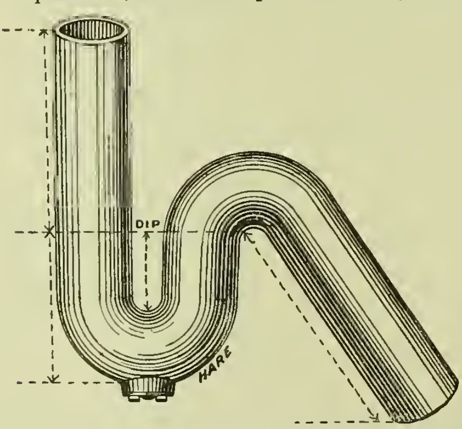


Fig. 274.—Drawn Lead Syphon, with Cap and Screw.

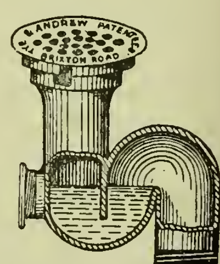


Fig. 275.—Sink Trap.

Syphon.—A much better construction is to provide a drawn lead syphon with cleaning eye immediately under the sink (Fig. 274), so that the grease may be readily removed.

Tye & Andrew.—A special trap of this kind by Tye & Andrew, is shown in Fig. 275. It is a very good sink trap, and is extensively used. It is made of galvanized iron, with brass grating and screw eye. The galvanizing is liable to destruction from acids passing through the waste, consequently it would be much better to make it entirely of brass or gun-metal.

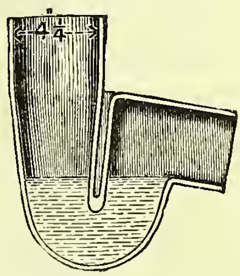
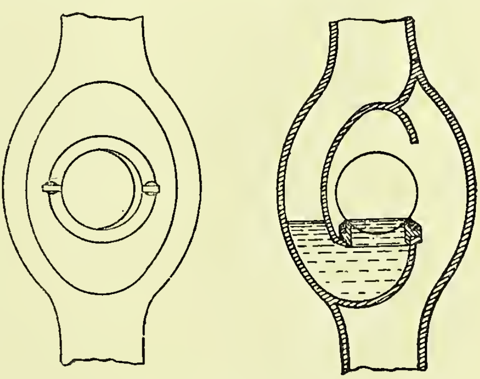


Fig. 276.—Hellyer's Anti-D Trap (small size).

The Anti-D Trap.—This trap was designed by Mr. S. S. Hellyer, and the "small" size for use with valve-closets, etc., is shown in Fig. 276. The water-seal is one and three-quarter inches,and the trap only holds two pints and a half of water ; thus the entire contents of the trap are changed by an ordinary flush of water. Mr. Hellyer states that " when fixed upon a properly ventilated soil or waste pipe—having its branch also ventilated —it cannot be unsealed by a discharge of the largest body of water, from a slop pail,or other vessel,that can be passed through a water-closet or slop-sink, no matter on what floor such fittings may be fixed nor the height at which they may stand above the trap. Nor can the seal of this trap be broken when fixed upon a stack of soil or waste pipe, provided that the branch on which it is fixed is properly ventilated, by any discharge of water sent into or through the main piping, either from a higher or lower level than that on which the trap is fixed—*i.e.*, the trap cannot be syphoned in properly ventilated soil-pipes and waste-pipes, nor can it be unsealed by the momentum of any discharge of water sent through it, whether from a slop pail or any other vessel." This trap is especially suitable for sinks and lavatories where there is a rapid discharge.



Figs. 277 and 278.—Jennings' Double-Seal Trap.

Double Seal—Jennings'.—Jennings' trap (Figs. 277, 278) is also sometimes used for this purpose. The water-way is closed by a light ball, which falls back into its place after the passage of the liquid. It has thus a double seal, and was designed to obviate the defect due to evaporation, but the accumulation of grease on the seating makes it uncertain in action.

There is a cleaning eye at the side for the removal of grease, etc.

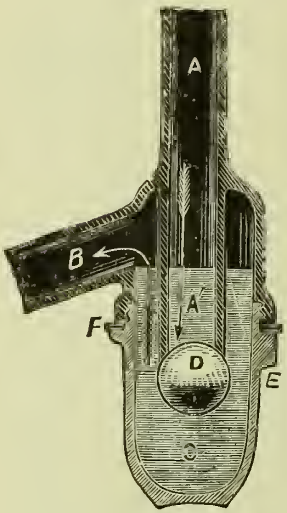


FIG. 279.—"Bower" Patent Sewer-gas Trap.

The Bower Trap.—Fig. 279 shows this trap. A.A is the inlet pipe, connecting directly with the sink or other fixture; B is the outlet pipe connecting with the waste. C is a cup-shaped chamber which always remains filled with liquid up to the level of the overflow into pipe B. The hollow india-rubber valve D is thus pressed up to the mouth of the pipe A, forming a second seal. E is a small lug on the cup to facilitate screwing on or removing the cup. F is a rubber gasket, and is intended to make a water-tight joint between the cup and the body of the trap. The chamber at bottom is made of either glass or lead, and is readily removed by unscrewing for cleansing. It also has a double seal, and the valve is likely to be more effective than in the former case, as a considerable amount of evaporation would be required to unseal it, and in the meantime the pressure on the seating is greater than in Jennings' trap.

It should be here remarked that it is best to use the simplest forms of traps for such purposes, especially now that the discharge pipe is never directly connected with the drain, and thus no advantage is gained by double sealing.

CHAPTER IX.

APPARATUS.

Latrines, W.C.'s.

Position of.—Latrines and urinals should be placed at a distance from an inhabited building, and, with this object in view, they are often built against walls with a lean-to roof.

Messrs. Doulton & Co., and Mr. G. Jennings, have supplied, in London, very excellent public urinals and w.c.'s in underground chambers built for the purpose. The walls are covered with white glazed bricks for cleanliness and to improve the light.

A place like this requires an attendant to see that the closets are not improperly used, and to keep them clean. This is not practicable with ordinary latrines, which have consequently to be of a rougher description, and situated where they will not create a nuisance.

W.c.'s for houses are, for convenience, built in connection with the houses. They should be confined to one part, and built over each other as much as possible. They should project out from the house, for both simplicity in arranging the water service and ventilation. They should also be cut off from the main house by well-ventilated lobbies; free ventilation and ample light are essentials to a properly arranged water-closet.

Water-closets should, if possible, have two windows, one facing the other. Where only one can be provided, it should be so placed as to cast ample light on the seat. The usual rule for sizes of windows in proportion to cubic contents of the room should be departed from in this case, and they should approximate to the size of the other windows in the house, extending to the ceiling, and being double hung.

Servants' w.c.'s, which are mostly on the ground floor, should be placed outside, as a rule; the minor inconvenience of having at times to approach it through the rain is more than counterbalanced by the decided advantage of atmospheric connection between it and the kitchen being effectually cut off. In town houses they are preferably situated in the area, in a front or back yard, entered from the open air, and ventilated into it.

Slop-sinks which approximate so closely to w.c. apparatus, should be placed in similar situations.

Interior urinals are only admissible in large buildings, and should be placed in much the same positions as w.c.'s.

Apparatus, Great Variety of.—There is a great variety of apparatus in use throughout the country, and improvements are constantly being effected in the patterns with the object of securing greater efficiency in operation, and in the exclusion of sewer-gas.

Latrines.—Latrines consist of an assemblage of two or more w.c.'s

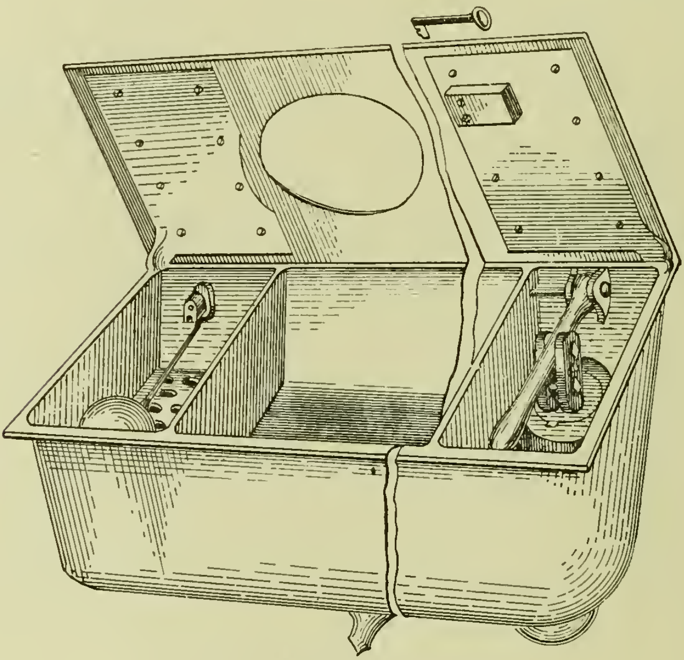


FIG. 280.—Macfarlane's Iron Latrine.

under one roof, and in consequence of their juxtaposition, the pattern is susceptible of considerable modification from any description of single closet.

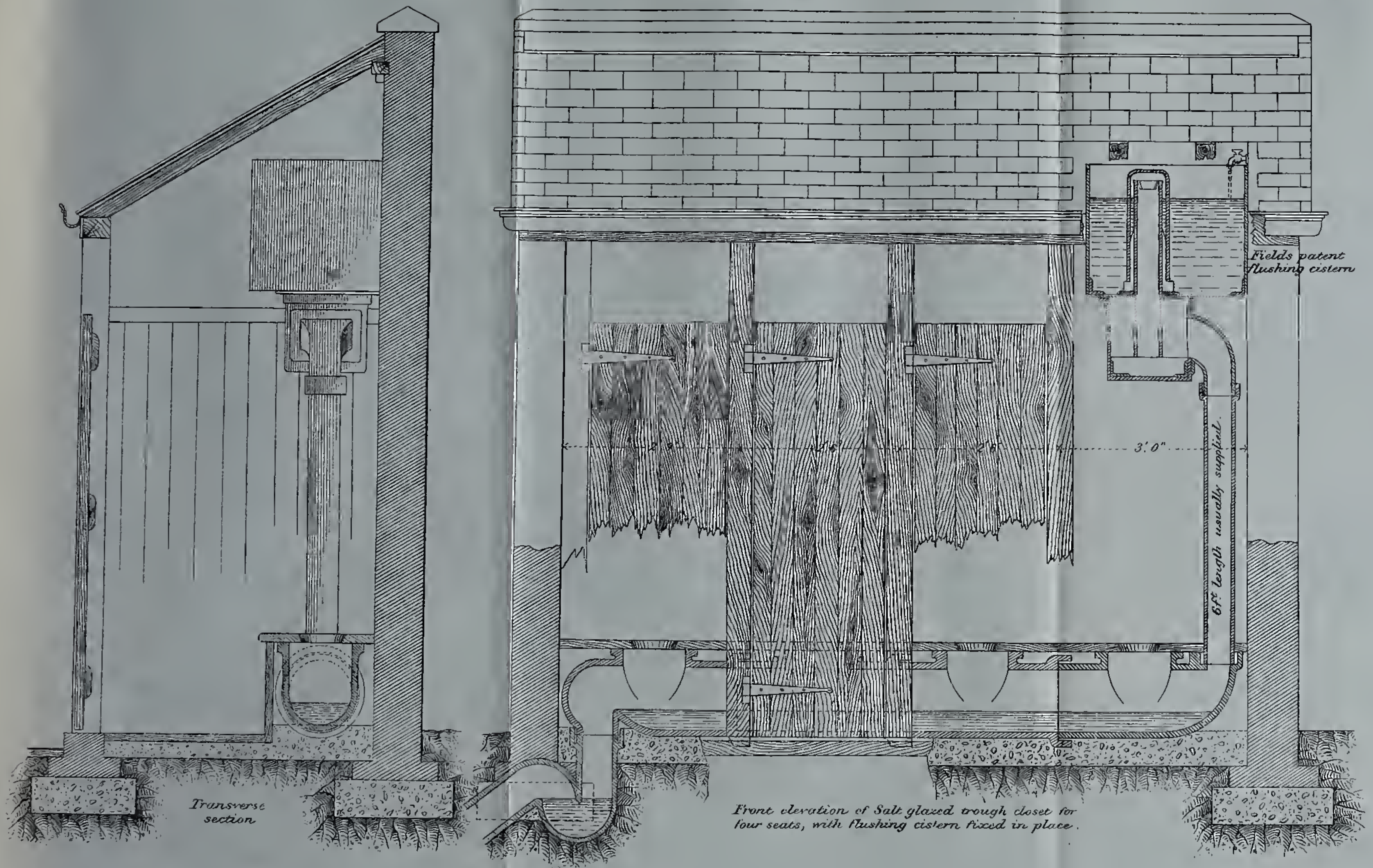
There are a great many kinds of latrines, amongst which I might mention one, in which the trough is made in compartments of stoneware, by Messrs. Doulton & Co., and in a continuous length in cast iron by Messrs. Bowes, Scott, and Western, Mr. G. Jennings, and other makers, in connection with which an automatic flushing tank is used (*vide* Plate XIX.). It would be better to have a separate compartment for it, in which cleansing utensils might be stored.

Macfarlane's latrine (Fig. 280) was at one time much used. It consists of an iron trough, corresponding in length to the number of

TROUGH CLOSETS.

(Bows, Scott & Western.)

PLATE XIX.



Transverse section

Front elevation of Salt glazed trough closet for four seats, with flushing cistern fixed in place.

J. Akerman, Photo-lith London.

JENNINGS' LATRINE.

Section.

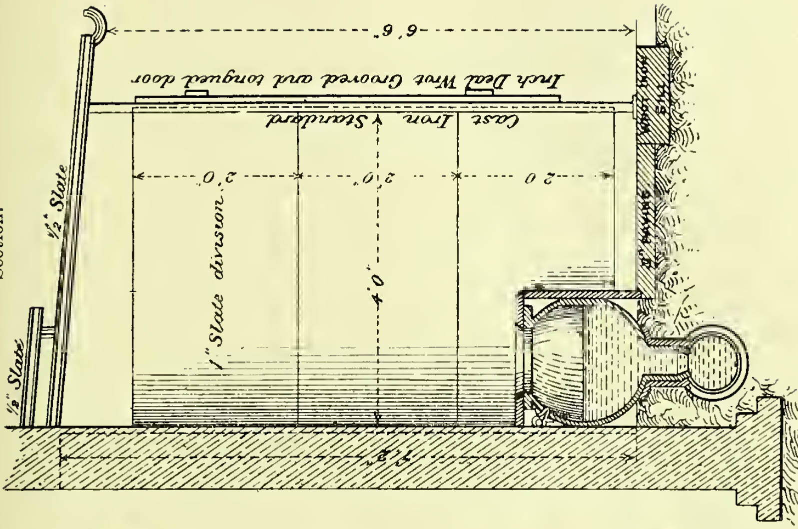


FIG. 282.

Elevation.

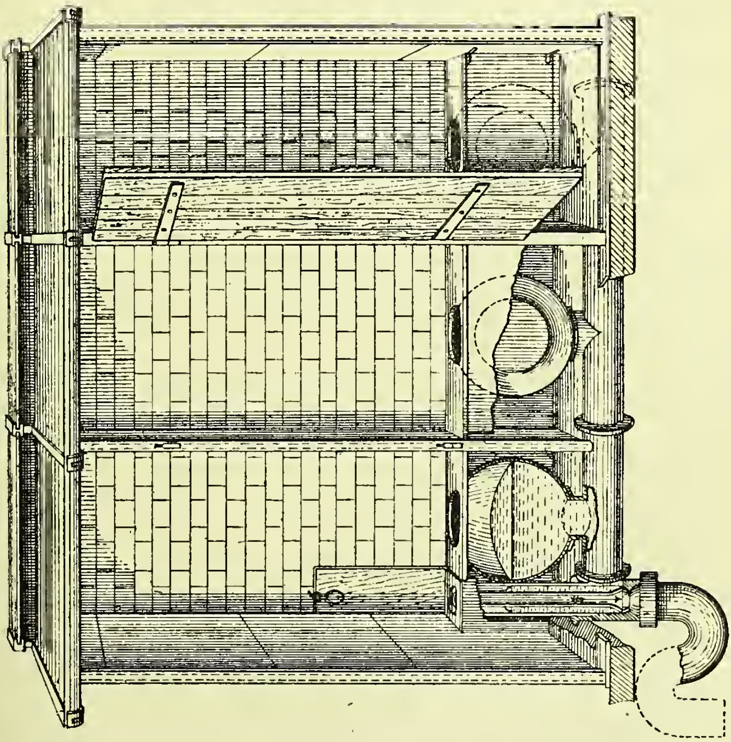


FIG. 281.

seats in the row. It has an extra small compartment at either end, as shown in the figure, the one to take a ball-cock to regulate the supply of water, which is thus kept at a certain level in the trough, the other contains the valve to close the mouth of the soil-pipe. It is flushed daily by filling with water, and lifting the handle which raises the plug. The trough can be cleaned out with a broom as the water runs in.

Jennings' latrines have also been used for many years. The pans are separate for each seat, as shown in Figs. 281 and 282.

They are connected by a continuous pipe underneath, and the water is supplied by an iron pipe at the back of the seat, with a branch to each pan. Nozzles are provided for each of these branches, to spread the water over the sides of the pan to cleanse it ; but this plan does not

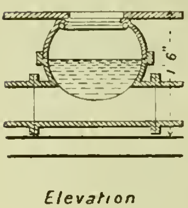


FIG. 283.

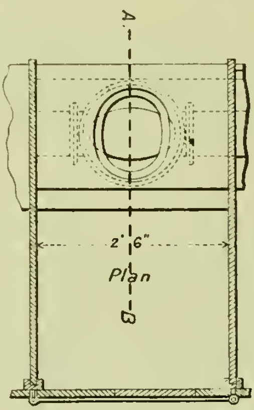


FIG. 284.

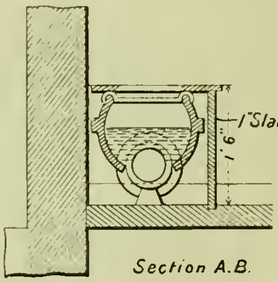


FIG. 285.

answer, and it would be much better to have a flushing rim to the basin, and I believe Mr. G. Jennings is making some on this principle.

The supply of water is controlled by a stop-cock, and the latrine is flushed by raising a valve in the end compartment. This valve has an overflow in it, so as to prevent the pans from being filled too full. Owing to the necessity for using a broom, occasioned by the insufficient flush to each pan, they very often get broken ; it would, therefore, be desirable, in setting them, to fill in round each with cement concrete, so as to support and strengthen them.

Jennings' Patent Automatic Latrine.—This latrine consists of a number of pans, somewhat similar to that shown in Figs. 283 to 285, ranged side by side, as seen in his ordinary latrine.

The automatic tank of the description shown in Fig. 363, page 349, is placed above the centre of the range, the discharge pipe from which is led down to the level of the latrine seats, where it branches off to the right and left, and passes along behind and immediately below the seats to the extreme ends of the range, where the water is admitted to the pans and tends to start the syphon action. The outlet consists of an S-shaped syphon at or about the centre of the range. At the highest part of this syphon a pipe is fixed, which pipe is attached to and receives a portion of the escaping water from the flushing tank, when the discharge takes place, thus forcing the air out of the discharging leg, and further inducing a syphon action. The syphon action is thus maintained until the whole contents of the range of pans are completely exhausted. The necessary after-flush then enters and refills the pans to a fixed depth. There are other patterns by Twyford, Boulder, and others.

Water-closets.—The essentials of a good water-closet apparatus are :—

1. The construction should admit of the trap being placed above the floor line, and as close to the basin as possible.

2. The material should be incorrodible.

3. The form should be such as to render the apparatus self-cleansing, and admit of ready access to every part.

4. There should be as few working parts as possible.

5. The flush should be so arranged as to deliver the water as rapidly as possible, and, at the same time, thoroughly scour the interior of the basin by one discharge.

In order to test a water-closet apparatus, the following simple method has been recommended, viz :—

"First cover the inside of the basin with lamp-black, then place a few pieces of paper (size about seven or eight inches square) on the covered surface.

"Next throw into the basin two or three apples, and a cork or bung, the latter is best. Discharge the flushing apparatus used in connection with the water-closet. In good types the apples and bung will be forced out of the basin and trap beneath ; the lampblack and the paper will also be removed.

"The apples used for the above purpose should not be overlarge. They are considered to have the same specific gravity as fæces."

Great care should always be taken in setting w.c. apparatus, so as to ensure good gas-tight joints, or the consequences, even with the best apparatus, may be serious. The floor should be sufficiently stable, or the joints may work open. There should be no step up to the seat.

Clean-water Closets.

There is a great variety of w.c. apparatus to be found in buildings, some of which are objectionable, for instance :—

Pan Closet.—The old pan closet (Fig. 286),* in which a copper pan or

* For purposes of ready reference and contrast, it has been thought desirable to group certain figures together on folding sheets, such as Figs. 286—299 (facing page 316), illustrating various Types of Water-Closets ; and it is hoped this arrangement will be found convenient.

cup (P) retains a little water in the bottom of the basin(B), is still being employed in many places. It is a very objectionable form, and delivers the contents into an iron container (R), on which the basin stands. The soil is splashed against the rusty interior of this enclosed receptacle, causing, after a time, the most offensive gases to be generated, which pass upwards into the house at each discharge from the basin. The arrangement is usually made still more foul by a D trap (T) placed beneath the container, as shown in the figure.

Valve Closets.—In this description of closet the movement of the handle should not allow the passage of sewer-gas into the house. The traps for these closets have often to be placed below the floor line and they are difficult of access.

Jennings' Valve Closet and Trap.—Jennings' w.c.'s (Figs. 287, 288) have been much used. They were a great advance on the pan closet, but have too many valves. Sewer-gas is also admitted when the valve is opened. They should be replaced by the simpler and more efficient apparatus to be mentioned later on. The Diagrams explain sufficiently the different descriptions which are to be met with, as well as their method of working.

Underhay's Valve Closet.—Underhay's valve closet has been much used during the last five years, both Nos. 1 and 2 patterns, which only differ in finish. Fig. 289 explains its action.

The water is retained in the basin by means of the valve under the pan, acted on by the weighted lever. The supply of water is regulated by means of a regulator; the supply pipe being $1\frac{1}{4}$ inches diameter, a good flush is obtained.

In some of the more modern patterns special flushing cisterns are also provided.

Tylor's Valve Closet is shown in Fig. 290. It is very similar to that of Underhay, except that the flap is hinged, so as to cover the outlet of the overflow pipe, and thus prevent it from getting choked. The syphon trap is above the floor line, and is provided with a cleaning cap. The ventilating pipe shown in the drawing is far too small.

Valveless Closets—The Hopper Closet.—The Hopper basin, conical shaped (Figs. 291, 292), with a syphon, is in general use for servants' w.c.'s out of doors. It has a spiral flush, but no flushing rim. It is a very objectionable form, owing to the great length of the basin above the water level. The sides of the pan are dry, and soon get fouled. The flushing arrangements are always defective, and the small amount of water that dribbles down the sides is not sufficient to cleanse the basin properly. Closets of this nature should never be fixed, especially as, where applied for servants' use, they receive less attention than those used by the other occupants of the house.

Attempts have been made to improve these closets by reducing the length of the basin and increasing the flush, but even then they are unsatisfactory.

Wash-out Closets.—Flush-out, better known as wash-out closets, which are made without any valves, are in great demand.

These closets have a basin which retains a small quantity of water after each discharge, and the mouth of the syphon is kept out of sight; the inside of the syphon and flushing arm are, however, liable to get coated with a deposit, and this is all the more likely to happen from the very fact of being hidden from view; the closet thus is apt to become unsanitary.

In order to ensure a supply of water being retained in the basin, Twyford's closet (Fig. 293) is supplied with an after-flush chamber, which being filled during the process of flushing, gradually discharges into the basin, thus making up any deficiency in the amount of water retained in it.

The "Lambeth" improved wash-out closet is shown in Fig. 294; it is made by Doulton & Co.

The manufacturers claim the following advantages for it:—

The hitherto great objection to this class of closet has been the difficulty in driving the soil and paper from the basin; it has, however, been overcome in the "Lambeth" improved flush-out closet.

Great care has been taken in designing the shape of the basin to get the greatest amount of water to remain in it, and at the same time offer the least resistance to the action of the flush.

The water enters the basin at the flushing arm A, exactly opposite to the discharge opening B, and by this means the whole power is utilised and a perfect flush obtained.

The flushing rim C is so formed as to wash the whole surface of the basin, at the same time allowing the main volume of the water to discharge immediately opposite the outlet.

Over the discharge opening is a plate D, which on removal gives access to the trap below, and allows of its being cleansed should foreign matter have been thrown into the basin. This prevents such matter being carried into the drain, with the probability of causing a stoppage where it cannot easily be got at.

The closet may be had with trap to shoot out or down, and a socket E is provided for inspection or ventilation, the trap being in every case made loose. A light iron standard F is provided, on which the basin stands, so that the trap may be turned any way to suit the position of the soil-pipe. This arrangement is further facilitated by the basin being circular on top.

The supply must be from a vacuum water-waste preventing cistern.

A seat action arrangement may also be applied to this closet (specially adapted to the use of servants, and for hospitals, factories, industrial dwellings, and public places) to prevent waste of water, the basin not being flushed until the user leaves the seat, when two gallons only are discharged.

In fixing the closet, care must be taken that the service pipe is so directed as to cause the water to strike the flushing rim of basin, and rebound to centre as shown.

The service pipe should enter the arm of the basin in a straight line. In all cases 1½-inch pipe must be used, and the closet flushed with a vacuum flushing cistern, and not by a valve.

Wash-down Closets.—A type of these closets, the "Simplicitas" (by Doulton), is shown in Fig. 295. The great advantage claimed for this pattern of closet is, that the full force of the flush is exerted directly on the water in the trap, as there is no cup to break up the current as in the case of the flush-out type, neither is there any part of the basin which is not subjected to the direct action of the flush.

Closets of this nature are made in great variety and by many manufacturers.

Duckett's Wash-down Pedestal Closet, the "Clencher."—This closet is represented in section in Fig. 296. The water surface is 7 inches by 5¼ inches, and the seal is 2 inches. The fall pipe should dip about an inch below the ware, and is made slightly bell-mouthed to form a recess for cement or putty, the latter can be used where the end of the pipe is made to fill the opening; the water conducted from the foot of the fall-pipe to the flushing rim by means of two oblique channels, which is considered an important feature in this closet, and the flush is said to be exceptionally strong with two gallons of water. The seat is hinged to a back rail, which is bolted to the ware, no brackets being required.

Shanks' Patent "Compactum" Wash-down Closet.—This closet is shown in section in Fig. 297; it has a large water surface, 8¼ inches by 6½ inches, and a deep seal to the trap, viz., 3 inches; it is claimed that a two-gallon flush of water is sufficient to thoroughly flush it. The manufacturers state it is made of a new body, "Vitro-Porcelain," which is vitreous throughout, non-absorbent, and "non-crazing." It is made by Shanks & Co.

Twyford's Patent "Deluge" Wash-down Pedestal is shown in section in Fig 298. It is made with a patent anti-fouling recessed back,

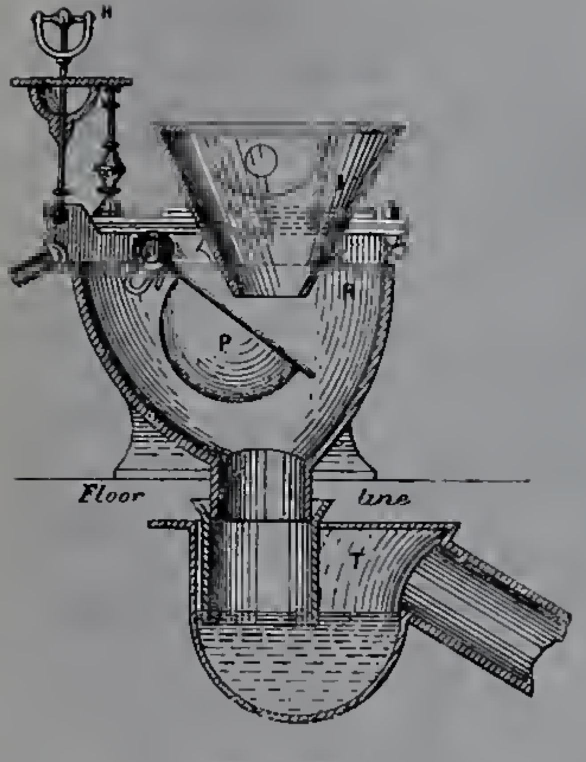
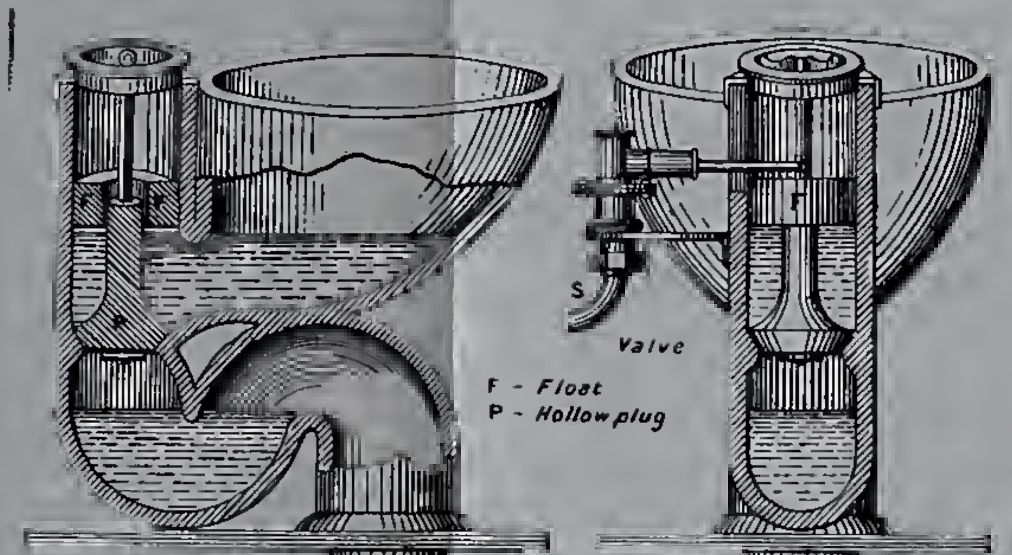


Fig. 286.—Pan Closet.



Figs. 287, 288.—Jenning's Valve Closet and Trap.

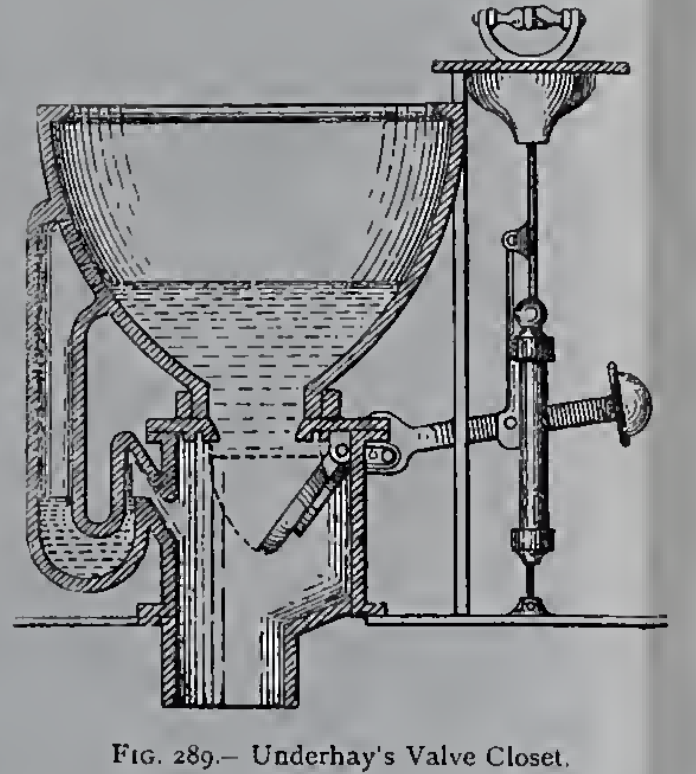


Fig. 289.— Underhay's Valve Closet.

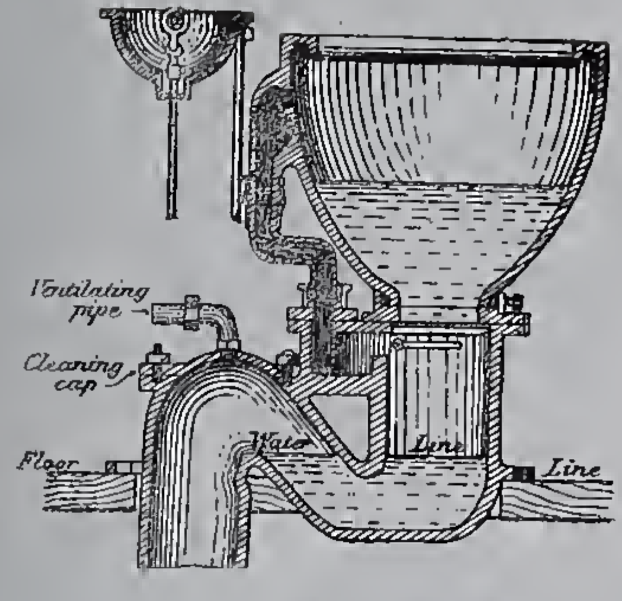
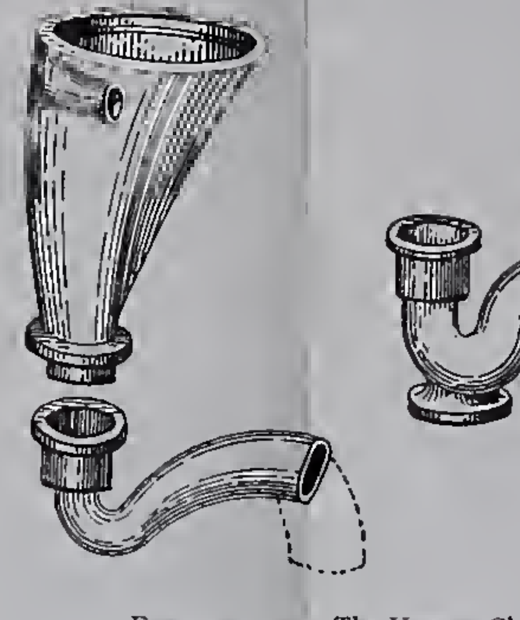


Fig. 290.—Tylor's Valve Closet.


Figs. 291, 292.—The Hopper Closet.

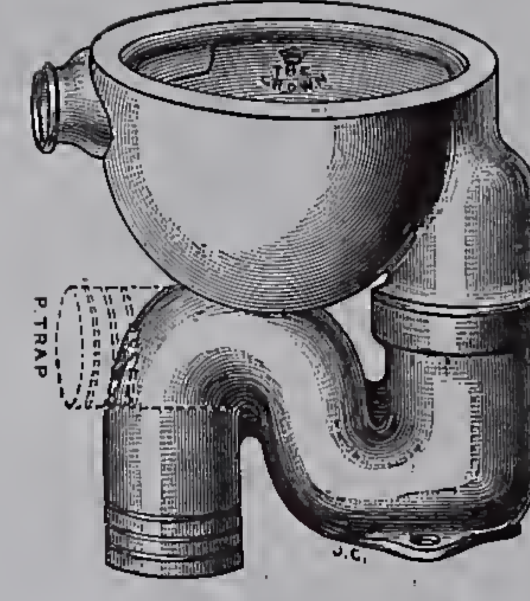


Fig. 293.—Twyford's "The Crown" W.C.

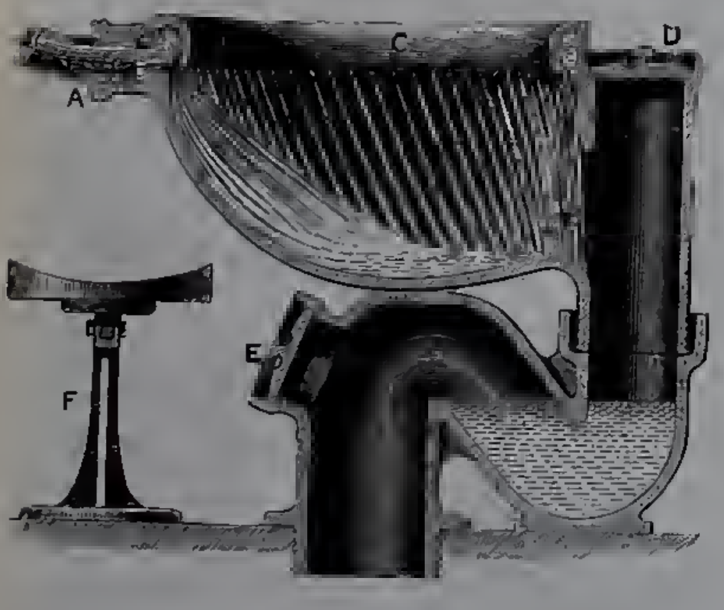


Fig 294.– The "Lambeth" Improved Wash-out W.C.

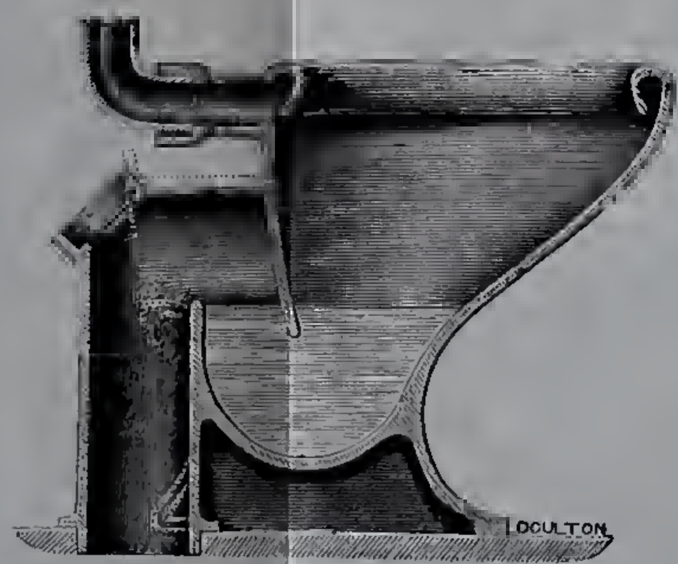


Fig. 295.—Doulton's "Simplicitus" Wash-out W.C.

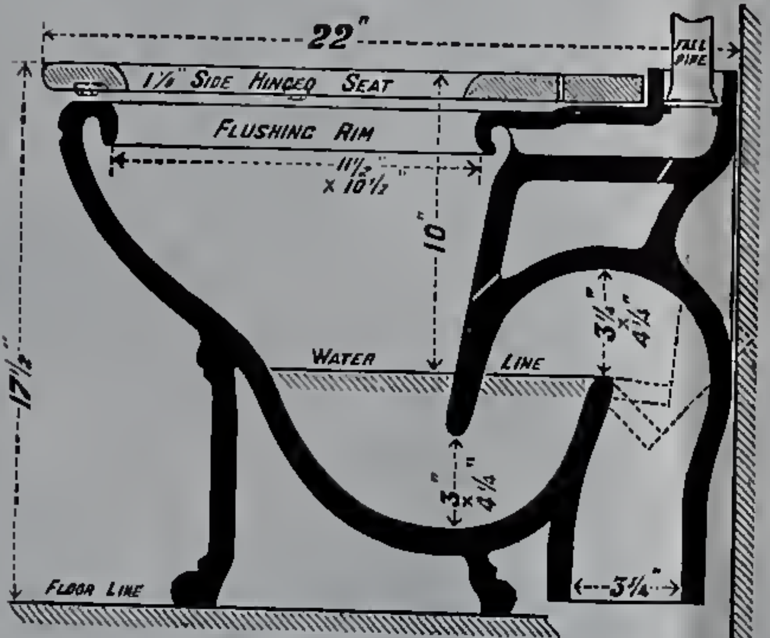


Fig. 296.—The "Clencher" Wash-down W.C.

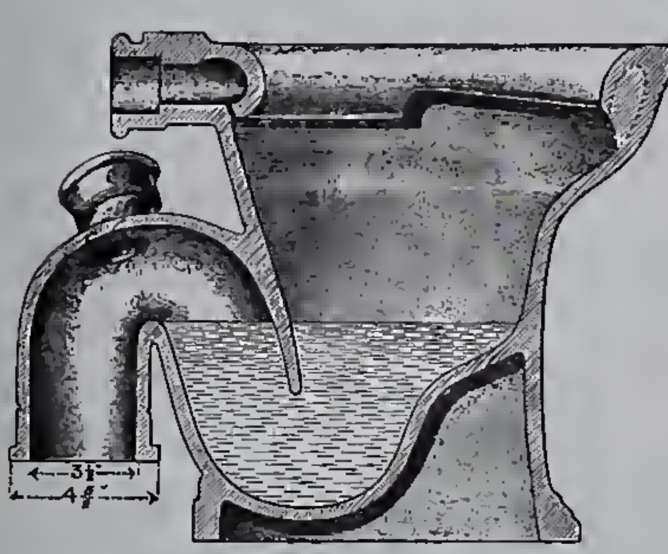


Fig. 297.– The "Compactum" Wash-down W.C.

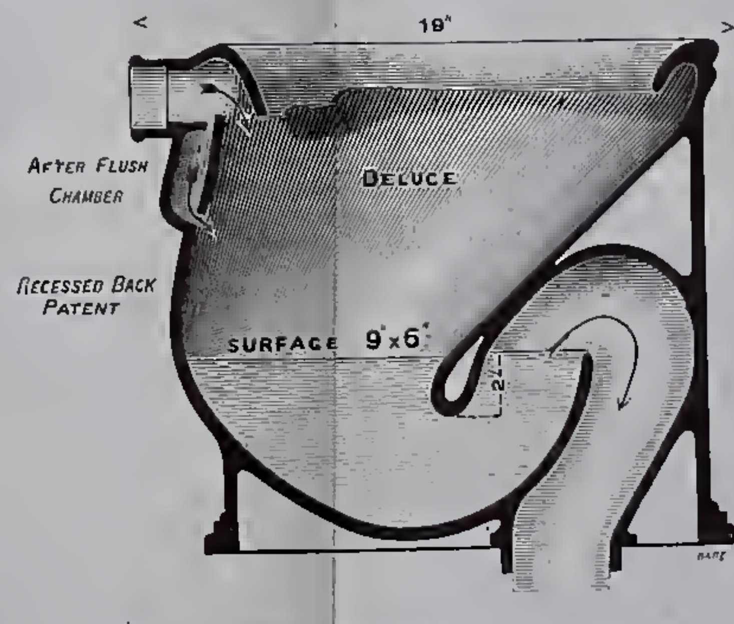


Fig. 298.– "Deluge" W.C., with Patent Anti-Fouling Recessed Back (Twyford's Patent).

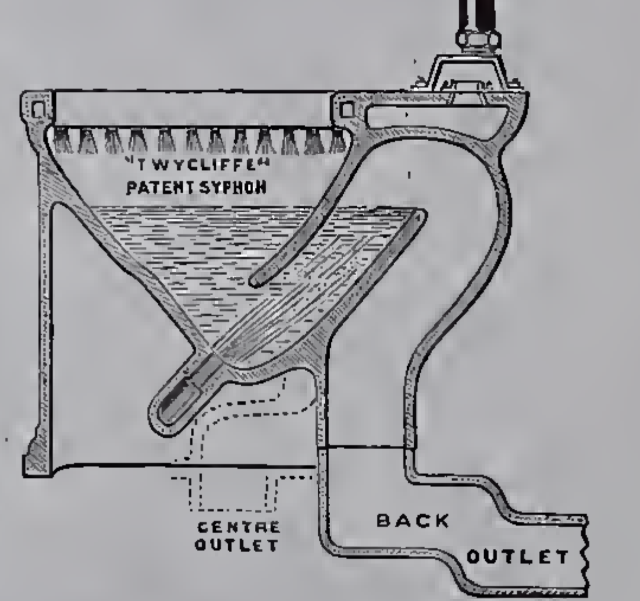


Fig. 299.– The "Twycliffe" Patent Syphon Pedestal W.C.

To face page 316.

and has a water surface of 63 inches, with a water seal of 2 inches in the trap.

The "Twycliffe" Patent Syphon Pedestal w.c. Basin, also made by Twyford, is shown in Fig. 299. It is claimed to be a perfect safeguard against sewer-gas and the evils arising therefrom, practically noiseless in action, simple in construction, reliable in action; that there is no complicated mechanism to get out of order, and that it can be easily fixed as an ordinary basin. It has an extra large water surface and a great depth of water seal (3 inches), and also a large body of water in the basin to receive and deodorise the soil.

The "Metropole" Wash-down Closet (Fig. 300).*—The manufacturers state that this is the only closet the basin of which can be removed from the lead pedestal and trap so that the plumber has full play to make a plumbing or wiped joint, and thereby doing away with the risky method of soldering a piece of lead pipe to the earthenware trap.

The force of the flush is exerted directly on to the water in the trap, ensuring a thorough clearing of the contents through the trap, and a complete cleansing of every part of the basin.

There is always a large surface of water in the basin and a deep water seal in the trap.

All parts being fully exposed and free of access, any defect can readily be detected and remedied.

It is constructed with a highly glazed earthenware basin and strong drawn lead trap, secured to a lead pedestal which is secured to the floor when fixed.

The separate parts are not united by screws, so that fracture by contraction or expansion is avoided.

The basin is bedded into the trap with any suitable material in the usual way.

The trap can be fixed at any angle to suit the junction or soil-pipe to which it is soldered.

The connection between the basin and the trap being above the water line, makes it physically impossible for an escape of sewer-gas to take place.

Should the basin be broken at any time it can be replaced for a trifling outlay, whereas the replacement of ordinary closets is, in many instances, very costly.

It is simple in construction, cheap, effective, durable, cleanly, easily fixed, and cannot get out of order.

It is made by Wright, Sutcliffe & Son.

Pedestal Closets.—These are made in a more or less ornamental

* Figs. 300, 301, 307, 308, 310—313, illustrating further Types of Water-Closets, will be found on the folding sheet facing page 322.

manner so as to conceal the trap,and avoid the necessity for wooden fronts; simple folding seats resting on small brackets from the wall, or on the closet, with intervening indiarubber cushions, being all that is necessary.

A sample of a pedestal closet by Doulton is shown in Fig. 301.

Connection with Soil-pipe.—The connection between the closet and the soil-pipe is a matter that requires the greatest care and attention, in consequence of its being situated on the drain side of the trap; any defect in it admits sewer-gas into the house. Foul water may also

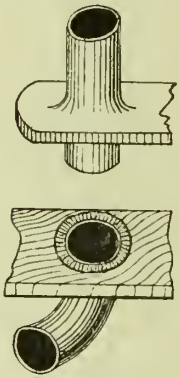
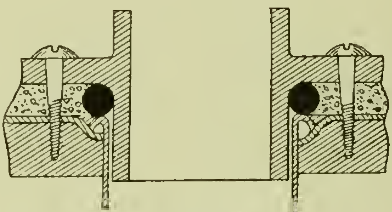


Fig. 302.



¼ full size
Section of jointing with soil-pipe
Fig. 303.

exude at this joint if it is defective, and produce contamination of the walls and ceilings at and below the floor line. Figs. 302 and 303 show the ordinary method of making this joint, though it is not entirely satisfactory, owing to the unequal expansion and contraction of the various materials employed, and possible want of skill on the part of the plumber.

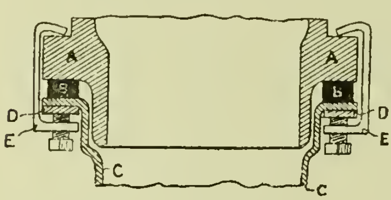
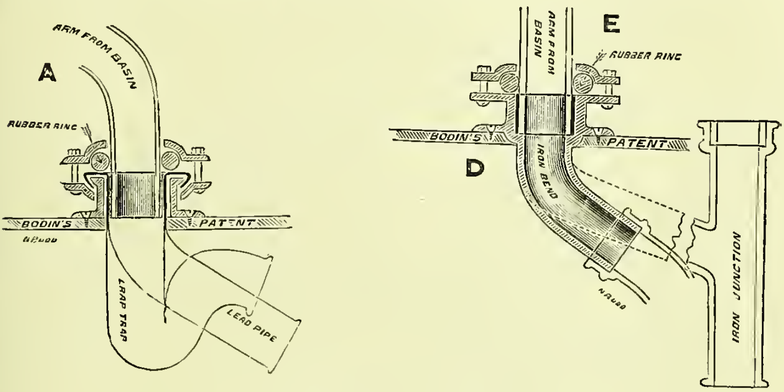


Fig. 304.

A more efficient and reliable joint is shown in Fig. 304. C is the lead soil-pipe; D a metal bearing ring; A is the flush of the basin; and B the indiarubber ring, which is compressed by the screw clamps E between the flush of the basin and the lip of the soil-pipe, thus making an air-tight joint.

Two of Bodin's special connections for soil-pipes are shown in Figs. 305 and 306. These joints are intended to make a secure but not rigid joint for connecting lead or iron pipe to the earthenware trap, "without plumber's solder, putty, paint, or brass thimble." There are other varieties of Bodin's "perfect joint," which enable it to be used in any position.

It is better to make the trap of the same material as the soil-pipe, viz., stout cast iron, or lead (Figs. 307 and 308). This enables the joint to be lead caulked in the case of iron pipes, or a wiped joint to be made if the connection is with a lead soil-pipe. The joint at C (Fig. 309) is another serious danger. It is difficult to get at it to make good work, and being very often concealed in the wall, there is no means of readily inspecting and testing its soundness. The "Safety" wash-down closet (Fig. 308) is provided with a strong cast-lead trap, and lead supports with holes for securing to the floor. It can be fixed in any



Figs. 305 and 306.—Bodin's Joint.

position to suit requirements. In fixing, the lead trap is soldered to the junction or soil-pipe (as shown in engraving). The trap, being independent of the basin forming the closet, is intended to act as a safeguard against the escape of sewer-gas into the building. It is manufactured by Wright, Sutcliffe & Son.

Another contrivance for obviating the danger of this particular joint is attempted to be met by means of a porcelain and lead joint. The attachment is made to the pan by means of a series of small grooves in the arm of the closet in which the lead socket is imbedded. This joint is capable of standing a pressure of 40 lbs. to the square inch.

The description of joint of this nature, supplied by Messrs. Doulton & Co., and called by them a "Metallo-Keramic" joint, is shown in Fig. 301. The lead soil-pipe and ventilating pipes are soldered to the sockets thus made.

Ventilating Openings are provided in many patterns of w.c. apparatus, as shown at B (Fig. 307). They are intended to provide against syphonic action being set up in the w.c. trap when closets at a higher level are discharged into the same soil-pipe, by admitting air to the highest part of the branch from the soil-pipe, and also to ventilate the traps.

The extra joint thus required within the house is most objectionable, and it is better to meet the difficulty by increasing the size of soil-pipe in proportion to the number of closets discharging into it, as already mentioned.

It is desirable to diminish the accumulation of sewer-gas in the branch between the trap and the soil-pipe by reducing its length and gradient as far as possible, consistent with an efficient discharge.

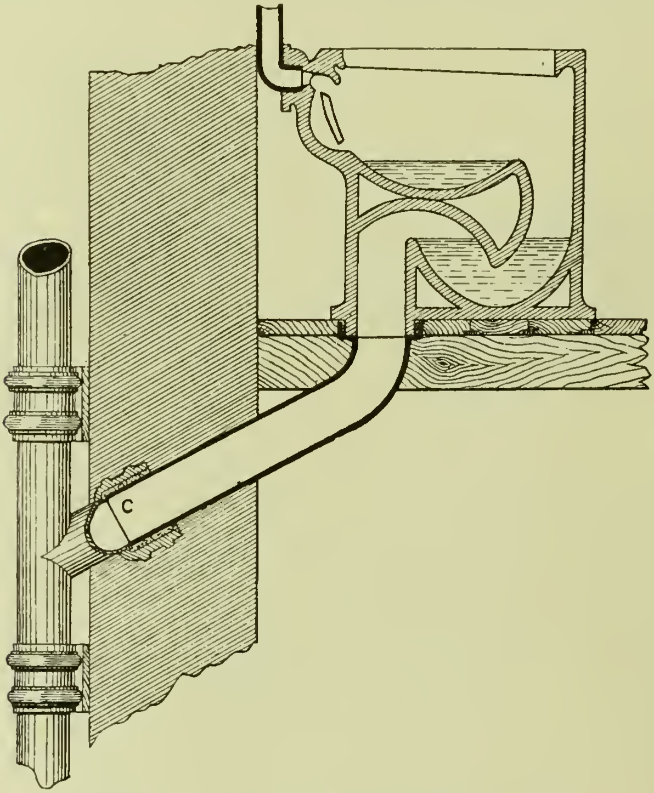


FIG. 309.—Ordinary Lead Connection with Soil-pipe.

The **"Self-ventilating Safety"** w.c. trap is shown in Fig. 310. It has been designed to avoid the defect which exists in most of the closets now in use of a joint in the soil-pipe between the trap and the drain.

The trap and connection with the soil-pipe are made in one piece, thus avoiding the dangerous joint between the trap and the soil-pipe, which continues to be a source of danger notwithstanding all the ingenuity and mechanical skill devoted to the subject.

The accumulation of gas in the trap is avoided by making the upper portion of the conduit through the wall horizontal, an ante-syphonage pipe can thus be attached at (S) ; it is thus self-ventilated, and other special contrivances, involving two dangerous joints inside the house, are rendered unnecessary.

The trap is made preferably of cast iron, and may be glazed on the inside so as to be durable and self-cleansing.

An examining eye is provided in the vertical attachment for soil-pipe, so that the inside of the trap can at any time be examined from outside the building.

The water seal is *three* inches. The pan can be set at any angle to the trap, so as to suit the special case involved, and traps obtained of different lengths (X) (see Fig. 310), beginning at two feet six inches and increasing by six inches each time.

The price of the two feet six inches size is about 26*s*. 8*d*., and the three feet size 28*s*., which is very moderate when it is considered that the whole of the plumber's work is saved.

The author is convinced the public rely too implicitly on lead as a safeguard to health and life, for he has seen lead traps and soil-pipes removed from a building, betraying externally very little of the horrible condition of the inside, due to corrosion and the consequent retention of putrescent matter on the surface of the lead. Such a condition of things is impossible with glass-enamelled traps and pipes, and it shows the extreme value sanitary engineers should attach to the provision of means for interior examination without having to take the apparatus, etc., to pieces. Many lives and great expense would be saved if this were attended to.

Two of these traps have been in use in Bermuda for a year, and when examined at the end of that time, were found to be perfectly clean on the inside and sound.

These traps are manufactured by Messrs. Shanks & Co., and are a patent, and a large number have been supplied for the use of the War Department.

Hellyer's Patent "Bracket Hygienic" (M) Wash-down Closet.— This closet is represented in Fig. 311, and is designed for fixing to a wall by means of a bracket or cantilever, so as to be entirely free of the floor, and unenclosed for sanitary reasons ; the basin has a large water surface 8 inches by 5 inches, and is provided with a lead seating and lead "anti-D-trap" for connecting with a lead soil-pipe by a wiped soldered joint. It should be used with "Flat-back" syphon flushing cistern, which discharges three gallons of water at each flush by one pull of the handle ; the cistern should be fixed directly over the closet as illustrated, and at a height not less than 6 feet 6 inches from the floor to the bottom of the cistern, with a flushing pipe of $1\frac{1}{4}$-inch bore.

"The Closet of the Century" (Jennings & Morley's patent, Fig. 312) is intended to secure the advantages of the ordinary cottage basin and trap, with the addition of the full basin of the valve closet without the mechanism necessary in the latter apparatus for its retention.

In the "Closet of the Century" a body of water, six inches in depth, with a surface area 12 by 10 inches, is retained, and by an arrangement of syphonage the complete removal of the contents of the w.c. after use is ensured. A 3-inch water seal is arranged for. The down-service pipe from the flushing cistern has two points of connection with the closet apparatus; one to the perforated rim, providing the ordinary supply to the basin for cleansing purposes, the other, introduced at the highest point of the descending outlet from the closet, being so arranged as to cause a natural syphonic action which, in operation, withdraws the contents of the basin with all the velocity due to the atmospheric pressure upon the water surface.

A secondary lead trap below the floor is suggested by the manufacturer for use with this closet, but it is stated that a weir bend is quite sufficient to ensure the effective action of the syphon discharge.

This closet requires a two-gallon flush, but it is stated that a two and a half gallon flush is preferable.

The "Scientia" automatically ventilated water-closet apparatus and lavement fittings is represented in Fig. 313. It embodies many different features in *one apparatus*, special arrangements being provided to render the "Scientia" closet the *ventilating lung* of the house.

The following is the apparatus provided:—

1. *The Water Closet* is of the latest and most approved type, with deep water seal, large water surface, and a direct-acting "wash-down" basin with perfect flushing arrangements, the ware being of a substantial kind, and of handsome design. Both sides of the trap are continuously ventilated, and there is such a depth of water in the basin as to completely cover all deposited matter.

It is a w.c. free from draughts, no cold air being thrown upon the body, and this in many cases has a very direct bearing on the health of the user.

2. *The System of Ventilation*, by which the "odours of use" are drawn off and conveyed away as soon as generated, and the w.c. chamber kept pure and sweet, is of the simplest and most effective kind. A gentle but constant renewal of air is secured throughout the day and night, not only in the w.c. chamber itself, but directly over the surface of the w.c. basin and urinal, thus subjecting the apparatus to a continuous process of "air washing," and this continuous ventilation is secured without cost for the suction power used, and is perfectly automatic, and requires no attention whatever.

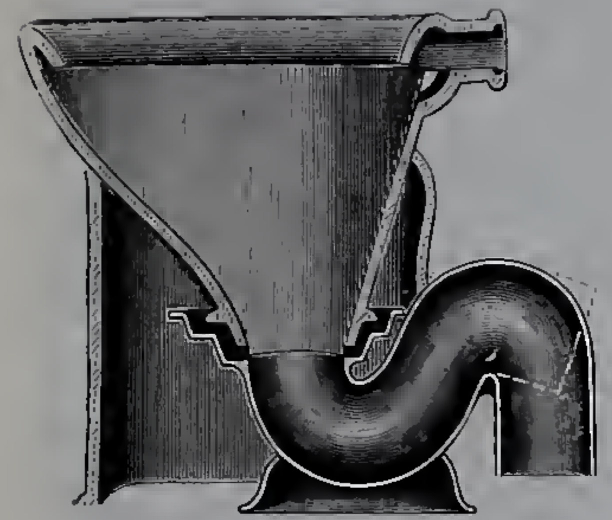


Fig. 300.—The Metropole Wash-down Closet with Lead Traps.

Fig. 301.—Doulton's Pedestal Closet, with Metallo-Keramic Joints.

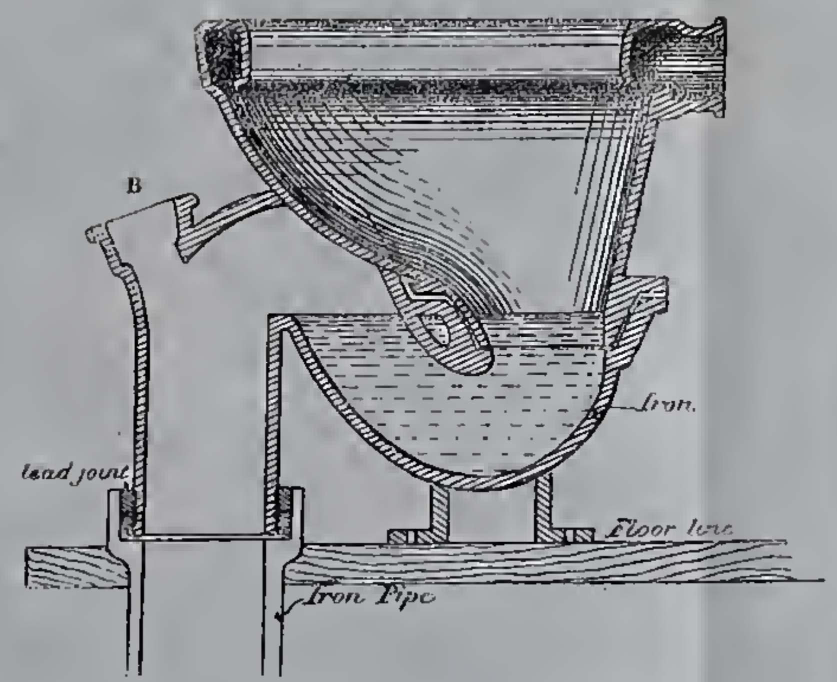


Fig. 307.—The "Hygienic" Closet (Hellyer's).

Fig. 308.—Closet with Cast Lead Trap and Soil Pipe.

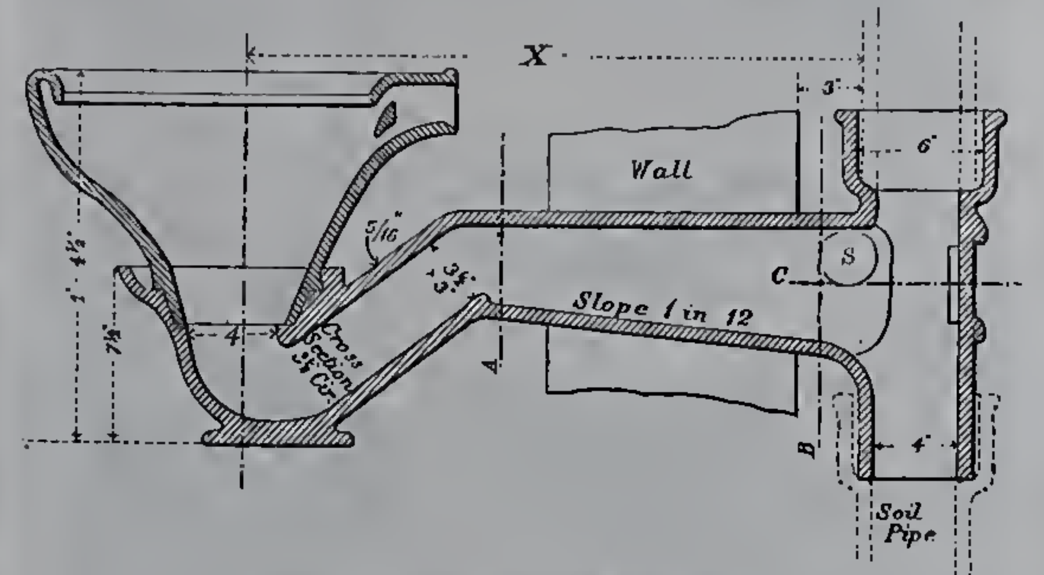


Fig. 310.—Self-Ventilating Safety W.C.

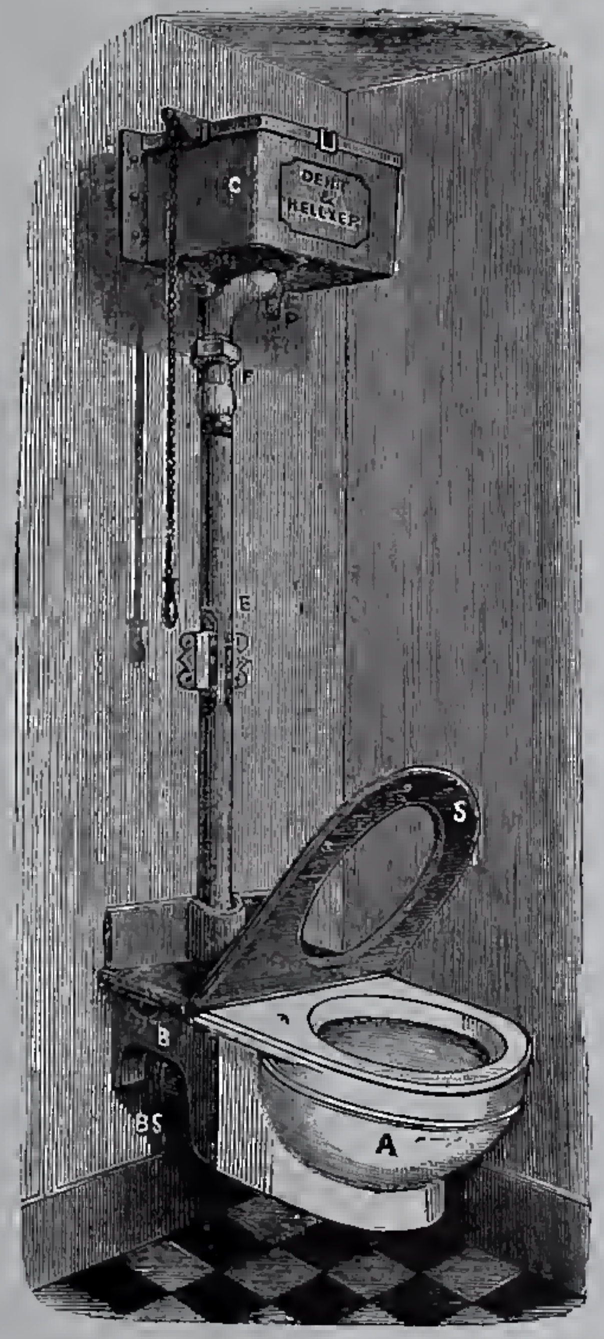


Fig. 311.—Hellyer's Bracket Hygienic Wash-down W.C.

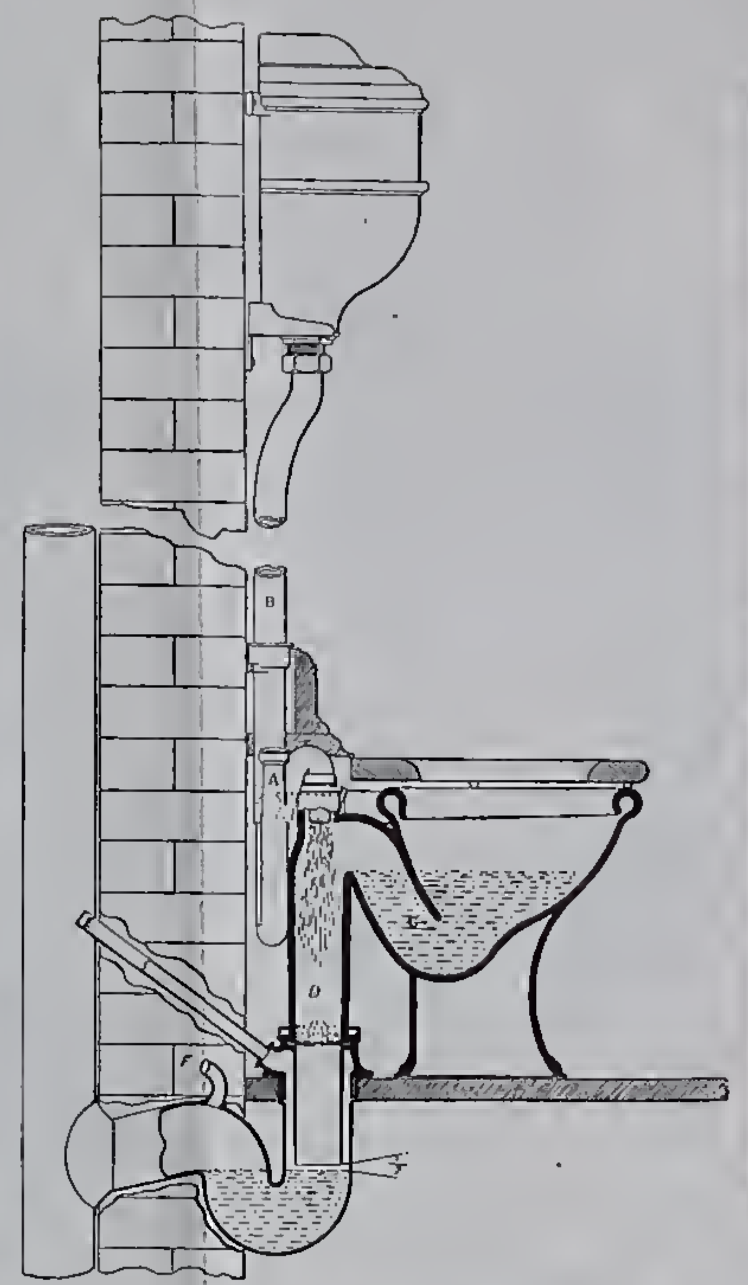


Fig. 312.—"Closet of the Century" (Jennings and Morley's Patent).

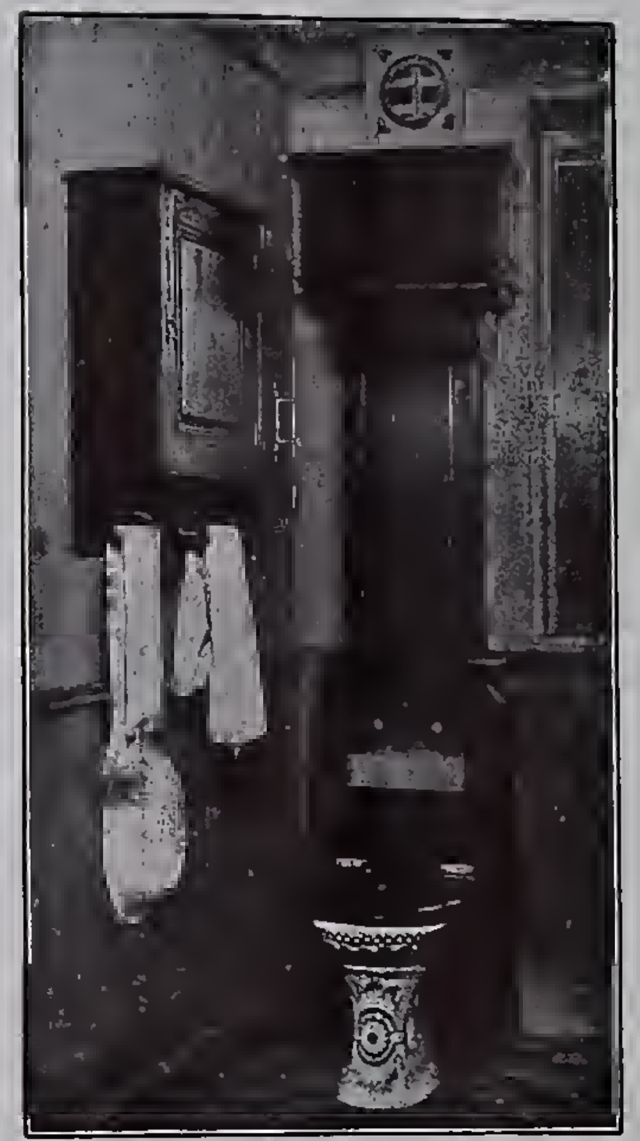


Fig. 313.—The "Scientia" Automatically Ventilated W.C. Apparatus and Lavement Fittings.

To face page 322.

The heat in the ventilating shaft renders the apparatus quite independent of external atmospheric conditions, and all fouled air and dangerous gases are at once carried away, and cannot enter the house. Hence, "the w.c. in the house" becomes as safe as if it were outside of the domicile altogether.

3. A concealed urinal for adults.
4. A lavatory.
5. A housemaid's "draw-water."
6. A capacious slop sink.
7. A fountain bath or rising douche.

Owing to its independent system of lighting and ventilation, the "Scientia" is peculiarly suited for positions where the ordinary w.c. could not be tolerated, and by its adoption much expense in structural alterations in our commercial and other buildings may be avoided.

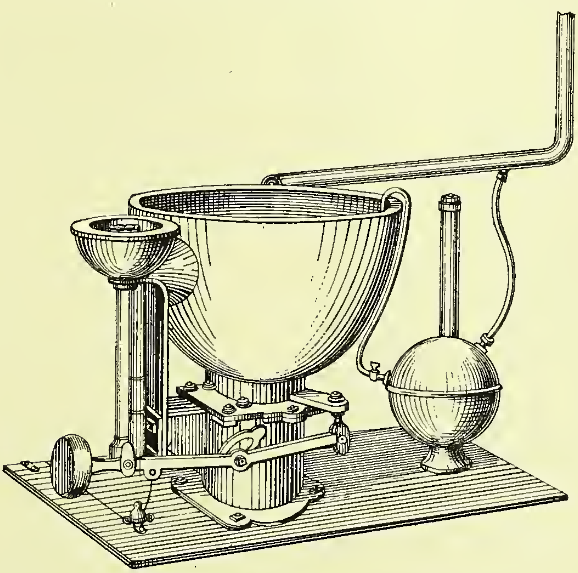


Fig. 314.—Disinfecting Apparatus used in connection with w.c.'s.

A Disinfecting Apparatus (Fig. 314) to be used in connection with w.c.'s has been introduced by the London Patent Automatic Disinfector Company.

The apparatus is applicable to any kind of closet or urinal. It is fixed out of sight, and contains sufficient disinfectant for 10,000 gallons of water, which is supposed, under ordinary circumstances, to last for one year without re-charging. Carbolic acid, or any disinfectant which might be desired, can be used, and a small quantity is discharged each time the closet handle is raised.

It is doubtful, however, whether it can be regarded as a desirable appendage to a closet. It is an addition to the apparatus, and requires to be replenished at intervals.

Its use recognises an improper condition of apparatus without effecting a remedy, as it merely acts as a palliative. The more satisfactory way of preventing the atmosphere of a w.c. from becoming offensive is to adopt a good and simple apparatus, and take care that it is kept perfectly clean, not only in the basin and trap, but outside and beneath the basin, and on the seat.

Cleanliness.—With the best kind of apparatus constant personal attention is necessary in order to secure perfect cleanliness, and even if the closet be properly used, the basin will still need cleansing beyond what it receives from the regular flush of water. In fact, wherever there is a w.c., it should be somebody's special duty to periodically rinse out the basin thoroughly with a brush kept for the purpose. The brush should be worked into the trap as far as possible, and likewise all round the upper part of the basin, the water being allowed to run while the brush is being used.

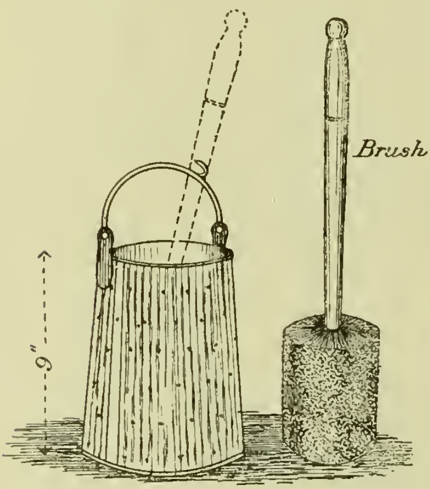


FIG. 315.—Brush, etc., for cleansing w.c.'s.

Fig. 315 is a description of brush suitable for this purpose. If the basin be very much furred, a little dilute acid will expedite the cleansing.

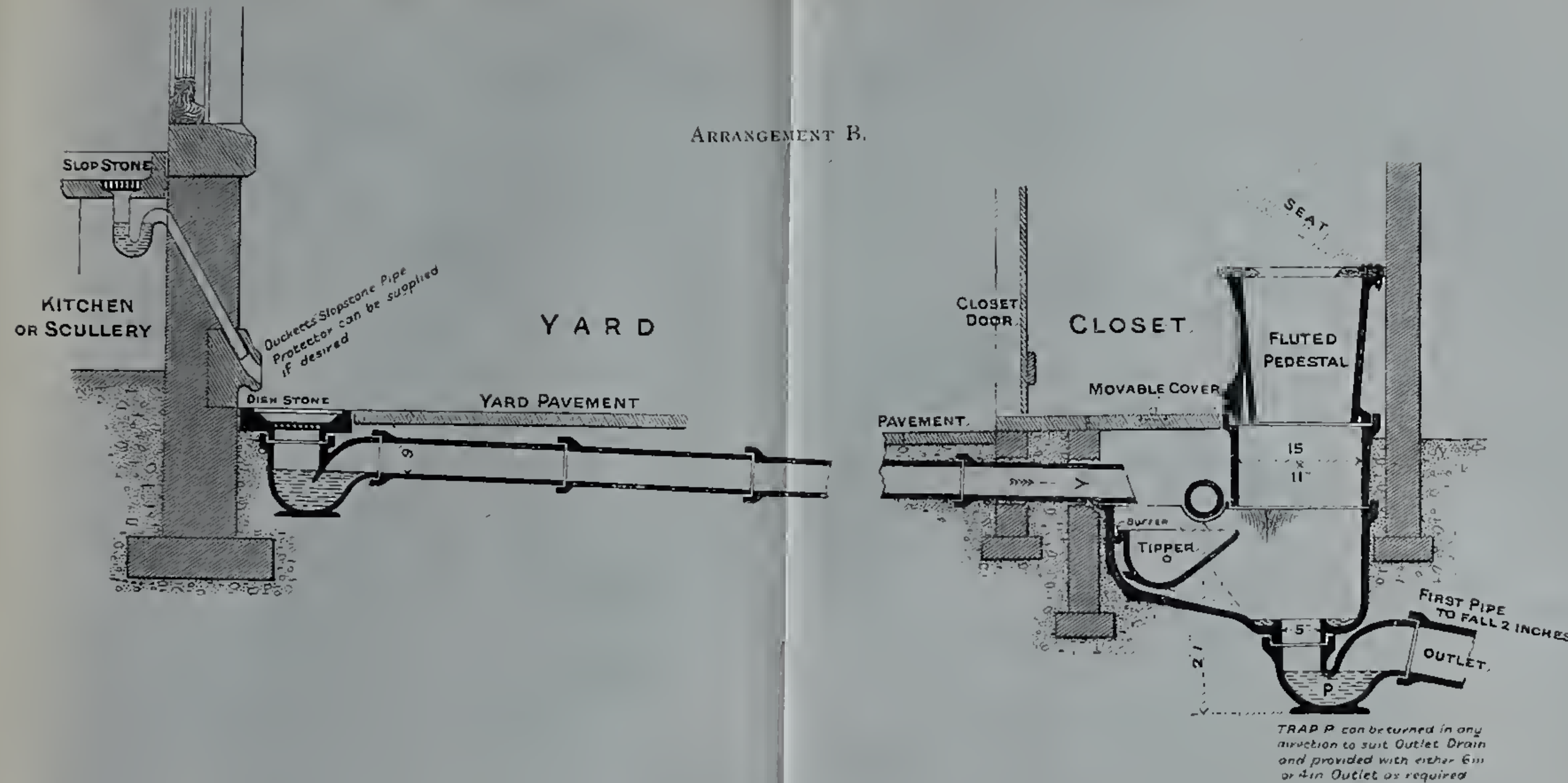
SLOP-WATER CLOSETS.

Ducketts' Slop-water Closets.—An improved form of closet, known as arrangement "B," was designed and patented by Ducketts in 1888. It is provided with a three-gallon tipper placed under the floor of the closet (Fig. 1, Plate XX.). This tipper tilts automatically, and the slop-water is discharged on to the annular basin and trap. The tipper is placed clear of the pan, so that it cannot be fouled by excrement, which is of great importance.

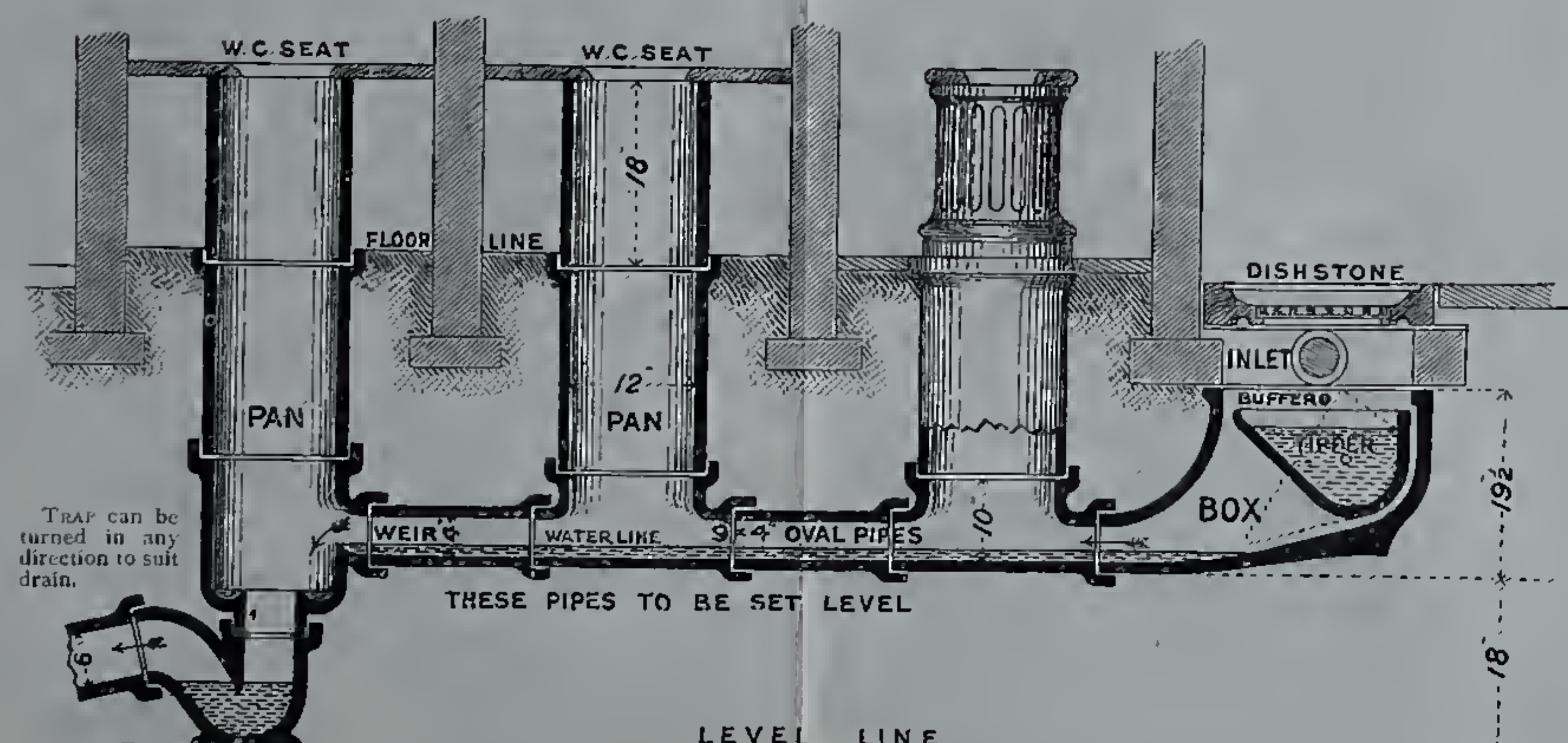
To prevent as far as possible large articles from being thrown into the closet trap, a special pan with a contracted opening at the bottom of quatrefoil shape has been introduced. The ordinary pans used, however, are either vertical, sloping, or plain; but in the case of the

ARRANGEMENT OF SLOP WATER CLOSETS (J. DUCKETT & SON).

ARRANGEMENT B.



ARRANGEMENT C.



pedestal the bottom is contracted to an overlapping oval twelve inches by nine inches, or to a quatrefoil as already described. The object of this contraction is to keep the pan below the floor free from soiling.

Multiple Closets.—Slop-water for flushing and cleansing a range of closets has been successfully utilised by Ducketts in their "C arrangement" (see Fig. 2, Plate XX.). Instead of having a small, intermittent supply of water in the channel, this arrangement provides for a frequent and powerful flush by a tipper flushing from five gallons upwards. By constructing a lip or weir at the outlet end of the range of closets, a quantity of water is retained in each closet, and a wide surface of water with little depth or volume is obtained by the connecting pipes being oval in section (nine inches wide, and four inches deep). Modifications of this arrangement are made to meet special requirements.

The "Perfect" Slop-water Closet (see Figs. 1, 2, 3, and 4, Plate XXI., page 326).—The extension pipe which is necessary in ordinary slop-water closets is done away with in the "Perfect" closet. This closet has been designed to prevent any soiling of the pan or basin, and is undoubtedly the best form of slop-water closet yet manufactured. The basin and trap are made of highly-glazed stoneware. The basin is of the well-known annular form, with the tangent inlet and central outlet. After the slop-water is discharged from the automatic tipper it swirls rapidly round the basin, cleansing it of any impurity, and then falls vertically from the annular channel about seventeen inches into the trap below, effectually removing any deposit.

This novel closet may either be fixed against the dwelling-house as illustrated, or it may be fixed at any reasonable distance from the house. In the latter case it is necessary that the floor of the closet be not less than two feet eight inches below the level of the dishbrick over the tipper. This arrangement is only applicable where the outlet sewer is sufficiently deep.

The arrangement illustrated requires only a shallow drain, and every part of the closet apparatus is easy of access and well ventilated.

The advantages claimed for the "Perfect" closet are—

1. It is a complete slop-water, wash-down pedestal closet.
2. It has no extension pipe or pan.
3. The trap can be reached with the utmost ease.
4. When fitted with a hinged seat, it can be used as a urinal.
5. Soiling, if not entirely prevented, is reduced to a minimum.

Advantages over Clean-water Closets.—In considering the advantages of slop-water closets, it will be well to remind the reader that they are not suitable for indoor purposes, but in all cases where physical conditions permit, they are recommended for outdoor purposes.

Slop-water closets are not as liable as clean-water closets to freeze in severe weather, as appears from the annual report of the Sanitary Inspector of Burnley for the year ending 25th March, 1895, in which it states that "during the year 6·5 per cent. of slop-closets were noted as being out of order, and 37·4 per cent. of clean-water closets have been reported defective, mainly on account of the frost."

There is a considerable saving of town's water effected by the use of slop-water closets, and a correspondingly smaller volume of sewage to be disposed of.

Clean-water Supply to Closets, Slop Sinks.—This should be obtained from cisterns specially provided for the purpose, and not direct from the water main, nor yet from the cisterns in which the water for other domestic uses, *e.g.*, cooking and drinking, is stored.

The best material for such cisterns is galvanized wrought iron or 14 S.W.G. in thickness, riveted at the angles, etc., though slate, and wood, lead lined, may be used.

In large houses, where several closets exist one above another, it may not be advisable to have a separate cistern for each, though, under any circumstances, the quantity of water consumed should be regulated so as not to waste the supply.

To govern the supply to these cisterns, a high pressure ball-cock, with horizontal action (Fig. 316*), should be fixed.

A standing waste is necessary, and it should discharge into the open air, where it can be easily seen.

They should be properly covered in at the top, similarly to those for drinking water, in order to prevent dirt, etc., falling in, and eventually interfering with the supply valves.

Further, a lead safe, with waste pipe, delivering into the open air, should be placed beneath the cistern to prevent injury to internal house fitments through leakage or overflow of water in the cistern.

The position of such cisterns will mainly depend upon the nature of the water-closets they are required to flush, but, as a general rule, they should be fixed in the roof of the building, between the ceiling of the highest floor and underside of rafters, with ready access.

At one time the water supply to a w.c. basin was obtained by placing a simple plug over the outlet pipe in a cistern, which was raised by means of a crank, and wire passing down to the handle in the chamber where the w.c. was fixed. The seating for this plug was very liable to get out of order, and the wire to stretch and break, and was a constant source of trouble.

* Figs. 316—323, illustrating WATER SUPPLY FITTINGS FOR W.C.'S, will be found facing page 328.

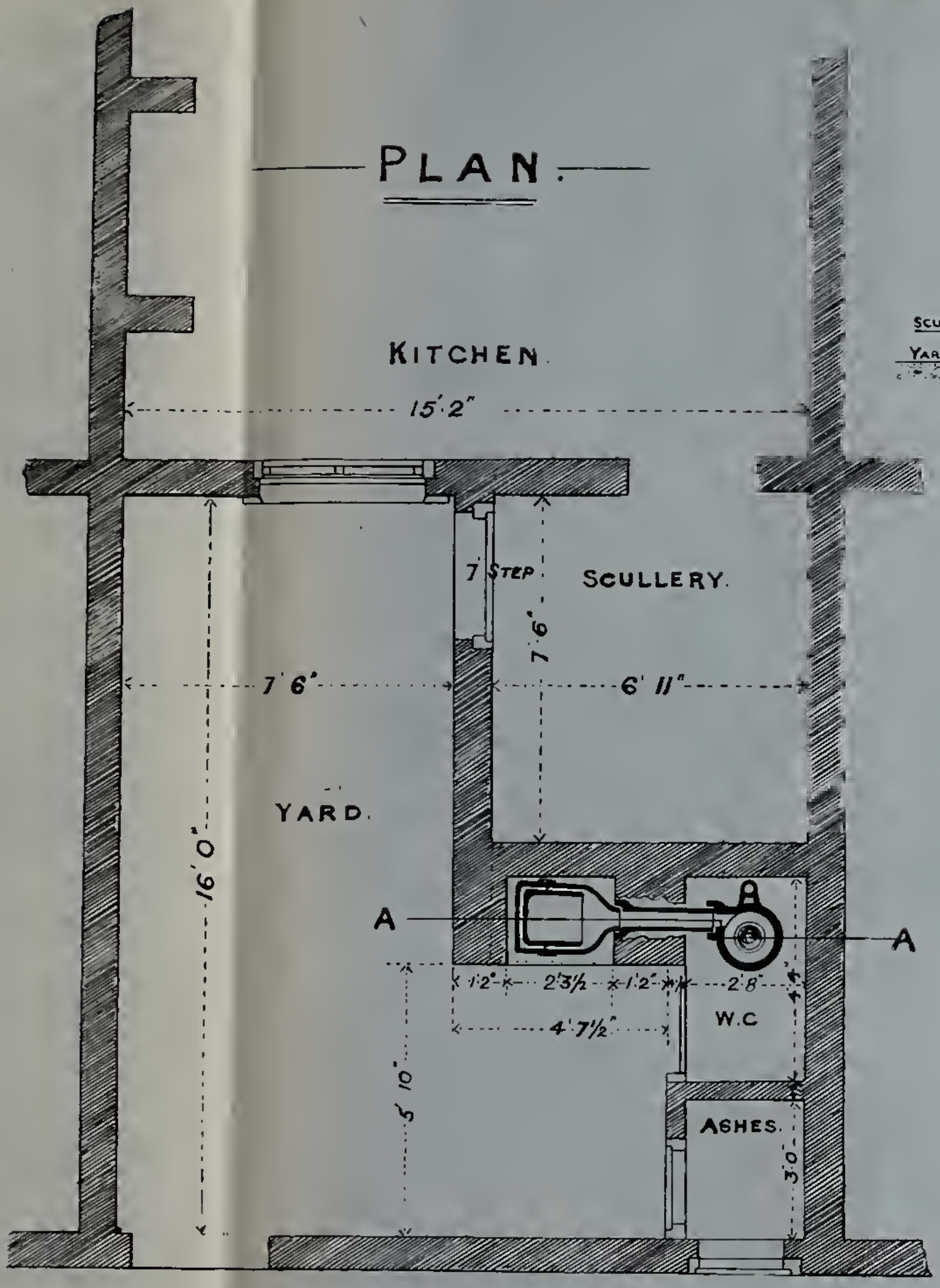


Fig. 1.

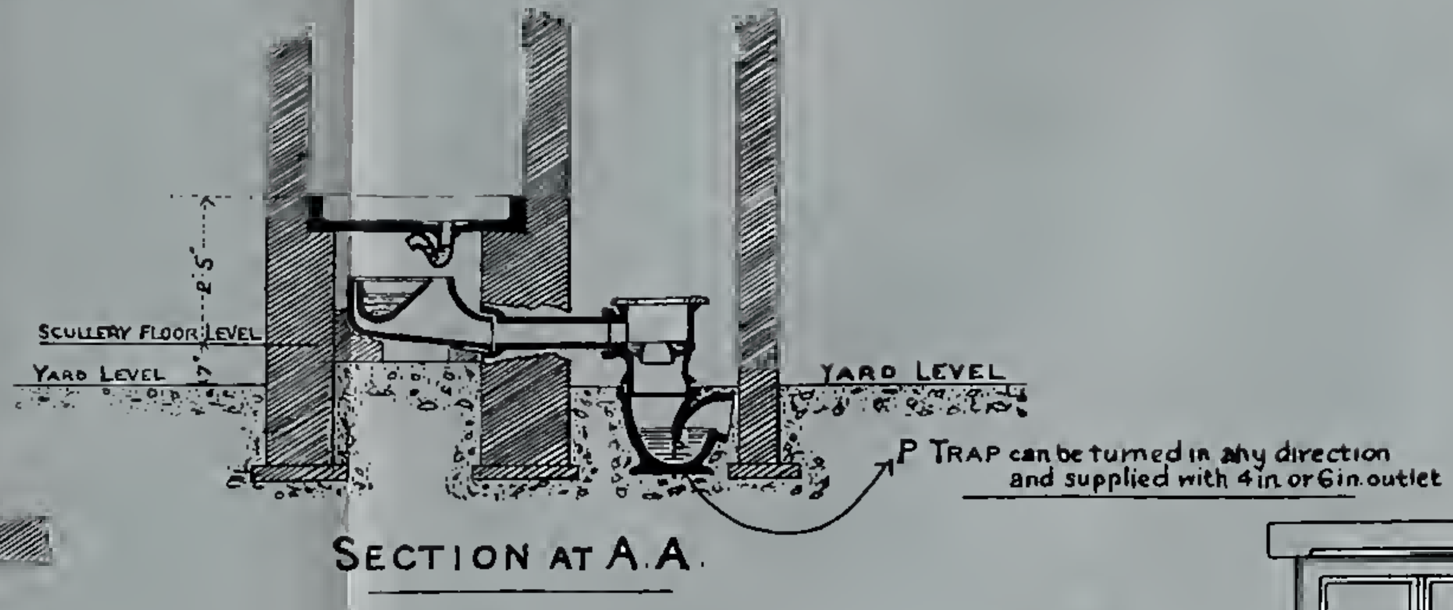


Fig. 2.

Quarter Inch Scale.

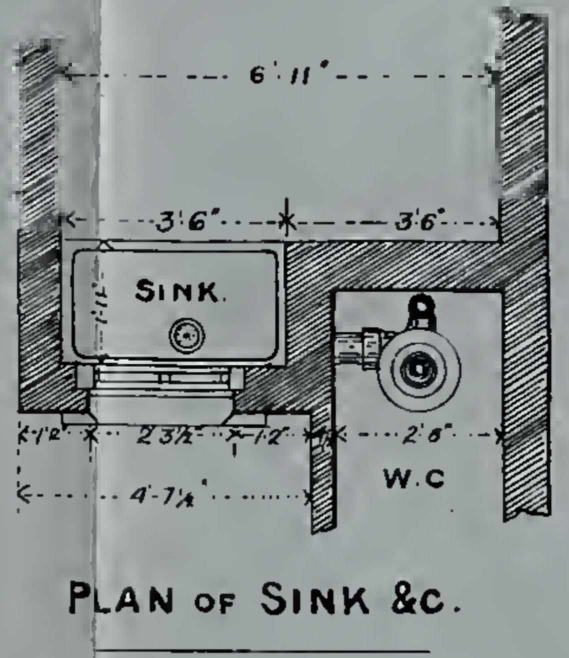


Fig. 3.

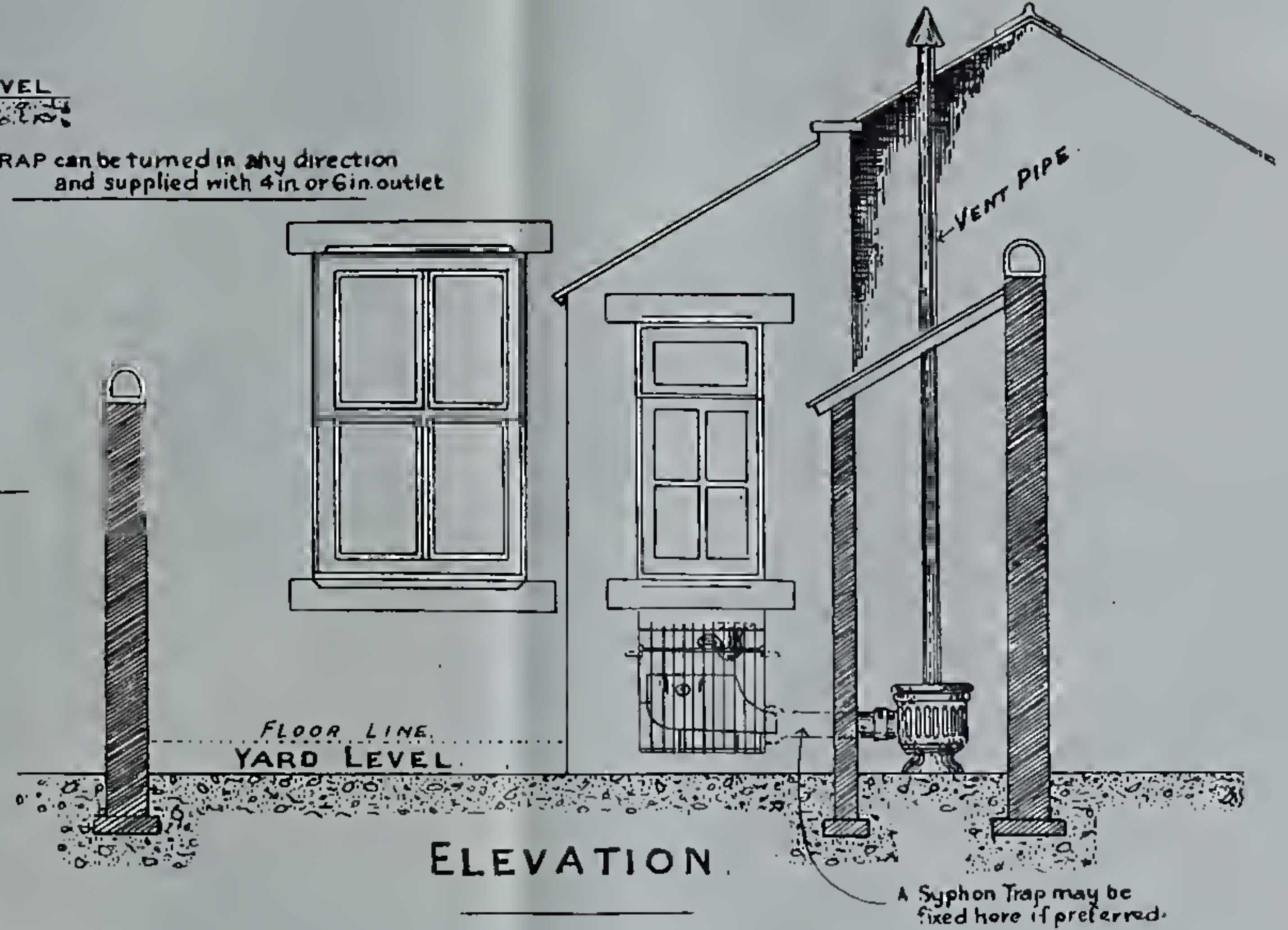


Fig. 4.

Note.—The "Perfect" Closet is applicable to other positions. This Illustration shows one arrangement only.

A tap in its simplest form, as shown in Fig. 317, was introduced to get over this difficulty, and prevent waste of water.

The sudden closing of the tap, however, produced a shock to the supply pipe—which was generally of lead—sometimes causing it to burst.

Both of these systems are found to be very wasteful of water, for as long as the plug in the cistern is kept raised, or the cock turned on, the water would flow, and possibly empty the cistern.

Where such flushing arrangements are found, the w.c. pan and trap are also generally defective, and if the main water supply to the house be "intermittent," then the w.c. supply pipe is liable to conduct sewer-gas from the basin to the cistern, and thus permeate the building.

Valves under the Seat.—A great advance on the preceding systems was the introduction of valves under the seat.

Some of the earlier patterns of these valves are those shown in Figs. 318 and 319. They are often found in water-closet apparatus, and are known as stool valves, and also as cottage valves.

They are divided into two classes, viz. :—

1. Those with stuffing-boxes.
2. Those with flexible diaphragms.

Fig. 318 shows a detail of that with the stuffing-box arrangement, which may be defined as the stool valve proper.

Fig. 319 is an illustration of a valve with a flexible diaphragm, which in the trade is called the cottage valve.

Neither of these valves have proved satisfactory in obtaining a good flush for the basin and trap, owing to the obstruction they offer to the flow of water, so that their capacity for flushing is not developed unless they are opened to the full extent, and, owing to the suspended weight, the valve is often shut down too quickly to admit of water being left in the basin.

Figs. 320 and 321 show external views of these valves, with handles, levers, and weights attached.

A "Bellows" regulator has been introduced, together with many others of a similar nature, to obviate these difficulties and to govern the water discharge in w.c.'s.

Fig. 322 gives an external view of the bellows regulator in position.

Fig. 323 shows the interior construction.

A is a valve attached to the spindle, S, and communicating between the interior of the bellows, B, and the casing, C. D is a disc, or stop, on the spindle, and T a tap, or cock, to regulate the discharge of air from the case, or cylinder, C.

When the handle of the closet to which the spindle, S, is attached is raised, the bellows, B, is compressed, air escaping into the case, C, through the valve, A.

When the closet handle is released the bellows, B, descends till stopped by the disc, D, the descent being regulated by the tap, or cock, T, through which the air in the case, or cylinder, C, is expelled.

Water Waste Preventers and Regulators.—In practice it is found that a flush of from two to three gallons of water, if properly applied, is sufficient to cleanse a w.c. basin and scour out the trap, and that it acts far better when discharged suddenly, and with a good head, than double the quantity would if allowed to run quietly through the closet. Water waste preventers and regulators have accordingly been designed with these objects in view, and the different descriptions will now be briefly described.

Care must always be taken in adopting any of these appliances to select those only which are constructed on sound principles, otherwise their employment may be attended with inconvenience.

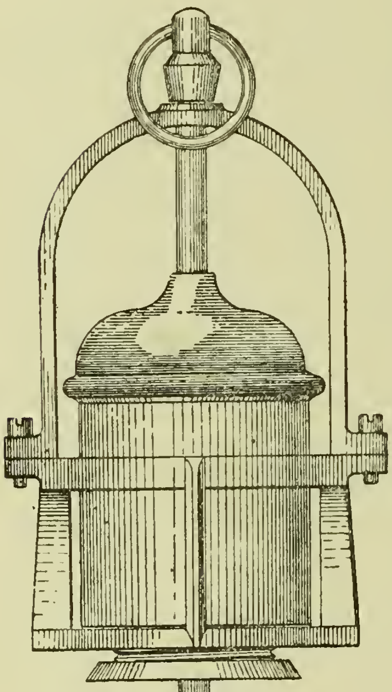


Fig. 324.—Tylor's "Waste Not" Cistern Valve.

Waste preventers may be divided into three classes:—

(1.) Those that are fixed in a general cistern, and which discharge a fixed quantity of water into each closet which such cistern is intended to serve.

(2.) Those which set free the contents of a small cistern, say two gallons, or of a compartment in a larger one holding a fixed quantity; and

(3.) Those that effect the same purpose less directly, by means of a regulator placed under the seat of the closet, allowing only a fixed quantity to pass through it.

All these contrivances, when used for valve closets, should have a means of securing the trapping of the basin by admitting sufficient water for that purpose after the valve has resumed its closed position.

(1.) **Waste-preventing Valves fixed in Cisterns.**—These valves are an improvement on the ordinary cistern plug arrangement previously mentioned, as they actually prevent a waste of water, due to the handle

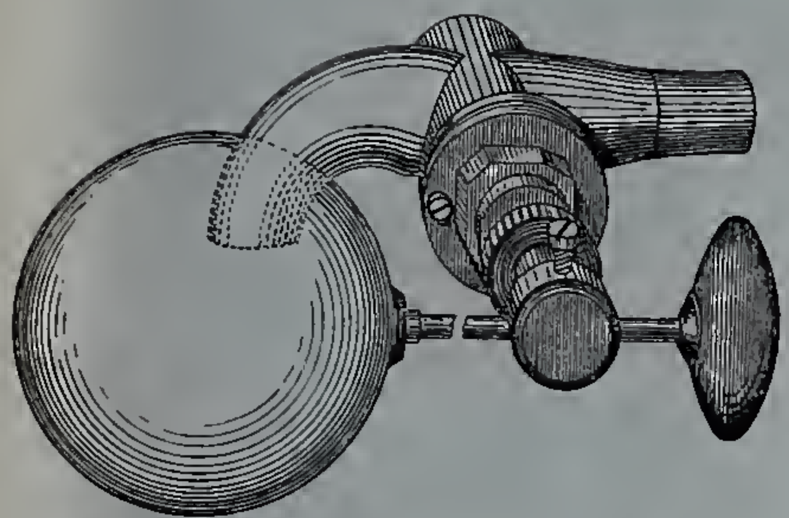


FIG. 316.—High Pressure Ball Cock.

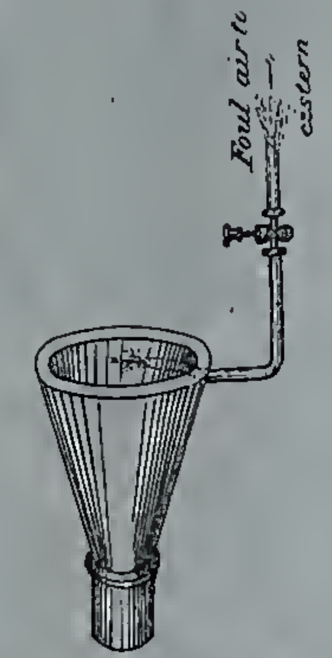


FIG. 317.—Hopper Closet, with Water Supply.

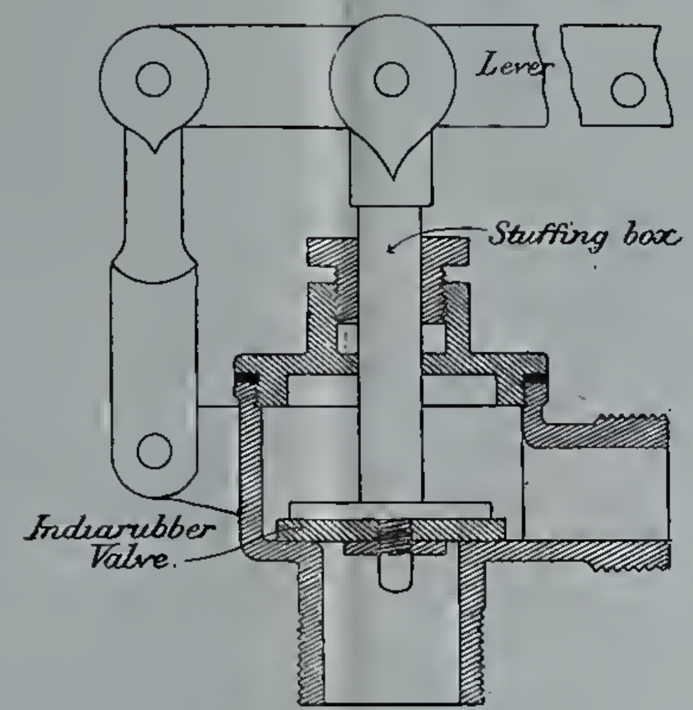


FIG. 318.—Stool Valve for Water Closet.

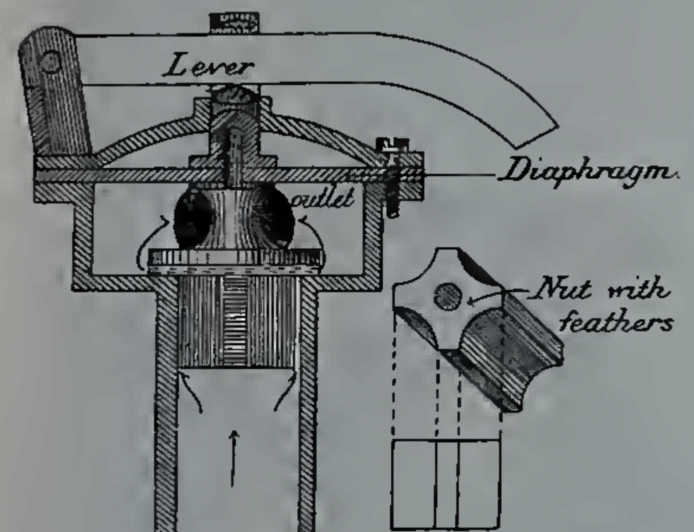


FIG. 319.—Cottage Valve for Water Closet with Flexible Diaphragm.

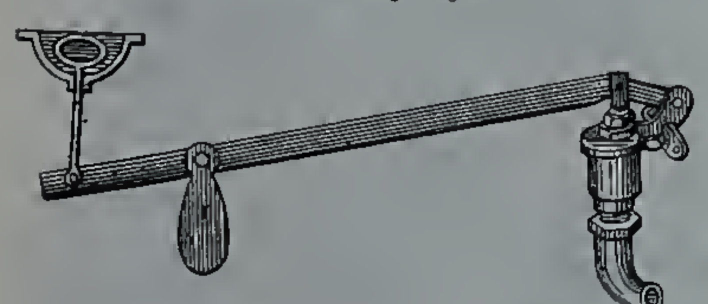


FIG. 320.—External view of arrangement with Valve, Fig. 318.

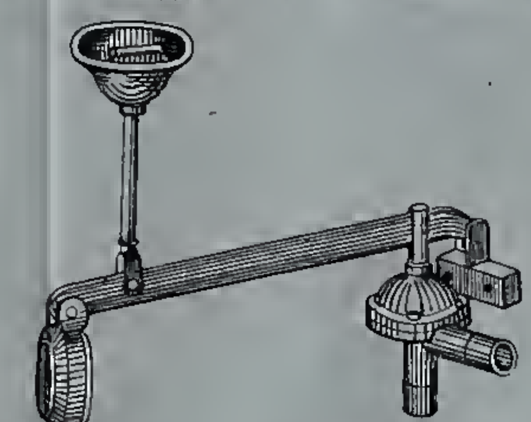


FIG. 321.—External view of arrangement with Valve in Fig. 319.

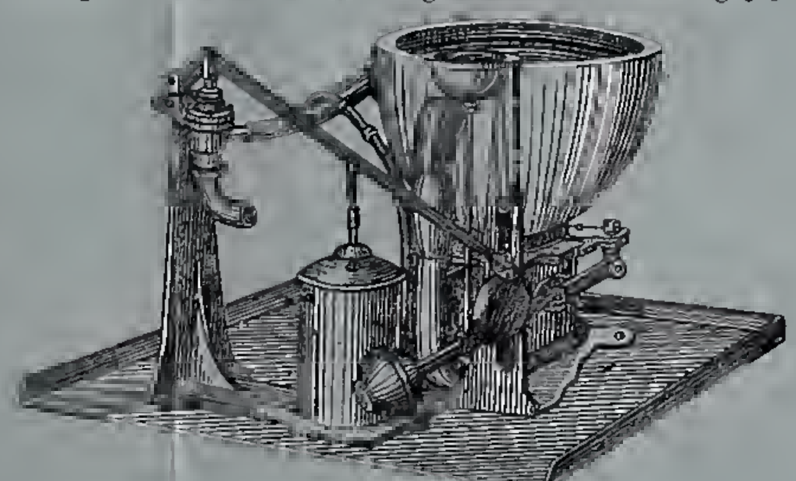


FIG. 322.—Bellows Regulator for governing the discharge in W.C.'s.

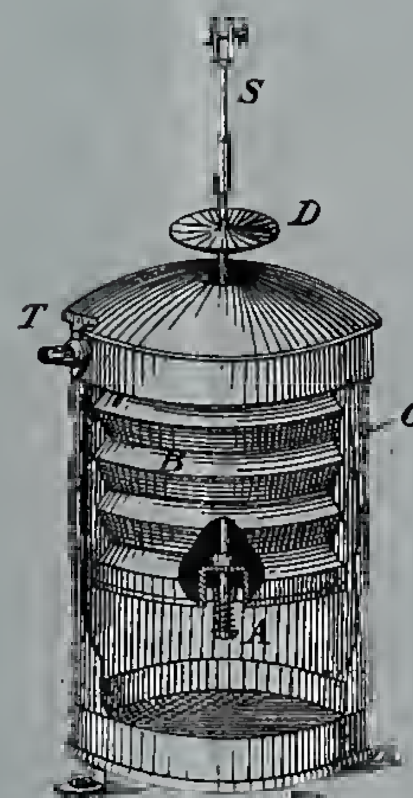


FIG. 323.—Interior Construction of Bellows Regulator.

To face page 328.

in the closet being kept raised too long, and ensure the use of a certain quantity of water, *and no more*, each time the closet handle is raised.

Such valves are always liable to derangement, and they therefore should never be put in places where it is not easy to get at them to rectify any defect.

Figs. 324, 325, show Messrs. Tylor's "Waste Not" cistern valve. It regulates the supply automatically, preventing an excess of water over that intended to pass to the closet, independently of whatever position the closet handle may be left in after opening it.

In this regulator the plunger, or follower, C, is fitted with a washer valve at bottom, and moves loosely up and down in a fixed cylinder, or case, F. E is a metal actuating carrier. When the ball lever of closet apparatus, which is attached to the spindle, A, is pulled up, it raises the metal actuating carrier, E, which takes up with it by capillary attraction, adhesion, or suction, the plunger, or follower, C, and opens the passage of water through valve.

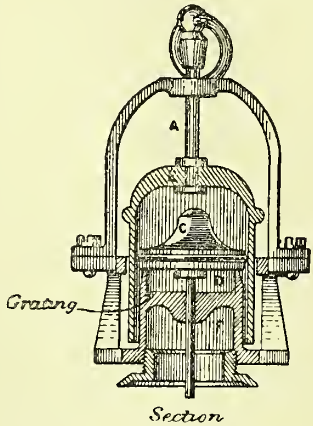


FIG. 325.—Tylor's "Waste Not" Cistern Valve.

When the spindle, A, is dropped, the metal actuating carrier, E, descends immediately, and assists in forcing the plunger, or follower, C, on to the seating, D, and the passage of water is closed.

When the ball lever attached to spindle, A, is held, or propped, up, the plunger, or follower, C, after being held up a short time by capillary attraction, adhesion, or suction, descends on to the seating, D, and closes of itself with the stream, having allowed the intended quantity of water to pass (usually regulated to two gallons).

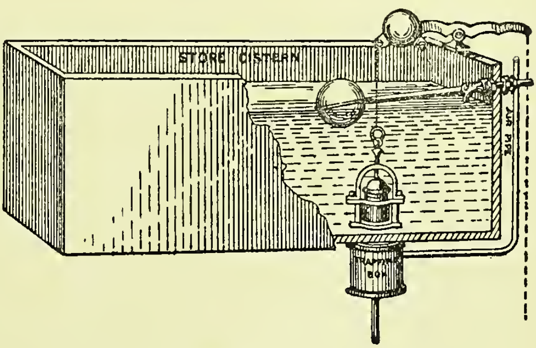


FIG. 326.—"Waste Not" Valve fixed in Cistern.

The adhesion, or capillary attraction, ceases, and the plunger, or follower, C, begins to fall, when the pressure within and without the metal actuating socket, E, is equilibrated or made equal.

Fig. 326 gives an illustration of this valve fixed in a cistern.

There are several other forms of valves of this nature, made by Messrs. Lambert, Messrs. Wallace & Connell, etc.

(2.) **Separate Waste-preventing Cisterns fixed in each Water-closet.**—This method appears to be the most efficacious in accomplishing the object in view, but care must be taken in fixing the cisterns to place them in an accessible position directly over the basin, but not too close to it.

The size of the delivery pipe varies with the description of cistern employed.

This class of apparatus is divided into two divisions, viz.:—

(a.) Those with valves.

(b.) Those with syphons.

(a.) **Valves.**—Fig. 327* represents a single valve, and Fig. 328 a double valve. The latter is more efficient in preventing any possibility of leakage due to a defect in the valve. The feed-pipe to these cisterns being very small, it takes a comparatively long time for them to re-fill. To obviate this inconvenience, another pattern (Fig. 329) is made, in which the cistern, supplied by the ball-cock, and containing from five to eight flushes, is divided into two compartments. The upper one contains the ball-cock, and the bulk of the water, and the lower one as much as is required for one flush only.

The valves in the lower sides of each of these compartments are so arranged on the lever that when at rest the top one is opened, and there is a free communication between the two compartments; but as soon as the handle is pulled in the closet, this communication is closed, and the lower valve is opened, so as to allow the flush-box to discharge itself into the closet basin, no more water than sufficient for one flush being allowed to pass until the handle is again released.

Another description of cistern, but suited to valve and flush-out closets, where a certain quantity is required as an after-flow to the basin, is that known as the "After-flush" (Fig. 330). This is effected by a small compartment, in which sufficient water is contained. This water is allowed to flow slowly down through a small orifice.

It should be noticed with these descriptions of valves that in order to empty the cistern, the handle must be restrained till the whole of the contents has been discharged, and thus, if too much hurried, the desired flush, which is necessary for sanitary purposes, is not obtained.

(b.) **Syphons.**—To effect the discharge of a fixed quantity of water, syphons are used.

Doulton's.—Doulton's vacuum water waste preventer, which is specially designed for use with his closet, is shown in Fig. 331. It requires a

* Figs. 327—341, illustrating VALVES AND FLUSHING CISTERNS, will be found facing page 332.

$1\frac{1}{2}$-inch discharge pipe when the fall is under ten feet, and $1\frac{1}{4}$-inch if over that amount, but is very noisy in its action.

Winn's Patent "Acme" Syphon Cistern.—The manner in which this water waste preventer acts is that the inverted cup being raised fills the syphon. To ensure its return to its original position, the lever arm is weighted (Fig. 332).

T. Crapper & Co. (Fig. 333).—The syphon action in this case is started by raising a valve, and the inlet pipe is led to bottom to prevent noise.

Twyford's National.—In Fig. 334 the syphon is shown raised off its seating; a rush of water is immediately established through the hole at the foot; when the handle is raised the syphon action proper is started. The seating is made of vulcanized indiarubber. The bent tube dipping under the water from the supply pipe is intended to prevent noise when the water is being replenished.

There is a chance of the valves shown in Figs. 333 and 334 leaking, as previously mentioned.

The "Westminster."—The "Westminster" water waste preventer (Fig. 335) can be obtained from Messrs. T. & W. Farmiloe, and seems simple in its action, which is started by moving the "displacer," D, without the intervention of any valves.

Shanks'.—Shanks' patent "reliable improved" valveless syphon waste preventing cistern (Fig. 336) is made in two varieties. The makers claim that the working parts are few and simple.

It is made with a well, or dip, in which an annular disc, D, works, and through the centre of this disc stands the syphon pipe. This disc is depressed by the lever rods, R, and immediately starts the syphon, emptying the cistern. It acts noiselessly.

Fig. 337 is a section to explain the action.

Fig. 338 is the second pattern, known as "No. 16A Reliable Improved." A section of it is given in Fig. 339.

The action in this case is different from No. 16. The disc, or plate, D, is made heavy, and, at rest, lies at bottom of cistern. When the handle is pulled this plate is raised, and upon the handle being let go, the plate falls by its own weight and starts the syphon. It is cheaper in construction than No. 16, but equally durable and satisfactory in action.

The "Stafford" Syphon Cistern.—This cistern is shown in Fig. 340, and has been designed to meet the requirements of water companies. It has a very powerful flush, is simple in all its parts, and reliable. It is made with good brass work, castings, strong chain, and polished handle, and is well put together and enamelled. It is made by Messrs. W. H. Bodin & Co.

Ducketts' A.1. Stoneware Syphon Plunger Cistern.—This cistern, represented in Fig. 341, has a very powerful flush (even with two gallons of water), and is more silent in action than most plunger cisterns. It is made of highly-glazed enamelled stoneware, and all the fittings are of the best quality. The stand-pipe is of lead, fixed a little above the top of the cistern to prevent secret waste. The lever is of strong cast-iron, and furnished with brass chain and ivory pull. The plunger is of enamelled stoneware. The flush starts with a pull-and-let-go. On the

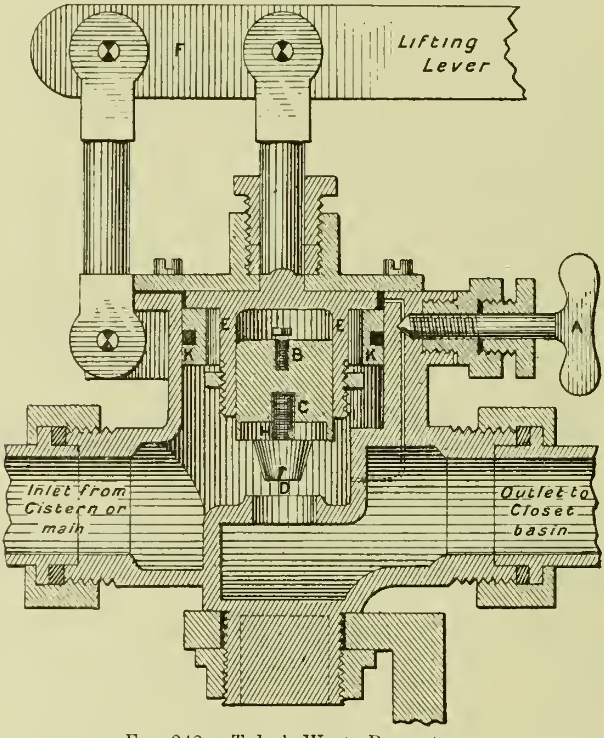


Fig. 342.—Tylor's Waste Preventer.

descent of the plunger the water rushes through the large circular openings in the plunger with great force. With only three feet of one and a half inch fall pipe it will flush two gallons in three seconds, or three gallons in four and half seconds. It is manufactured by J. Duckett & Son.

(3.) **Waste-preventing Regulators fixed under Seats.**—The advantages claimed for this class are that they occupy less space in the closet, and a number of closets can be supplied by the same service pipe from the cistern above. The disadvantages are that less force is obtained in flushing out the basin, which is an important defect, and the apparatus is not so durable, owing to the number of working parts.

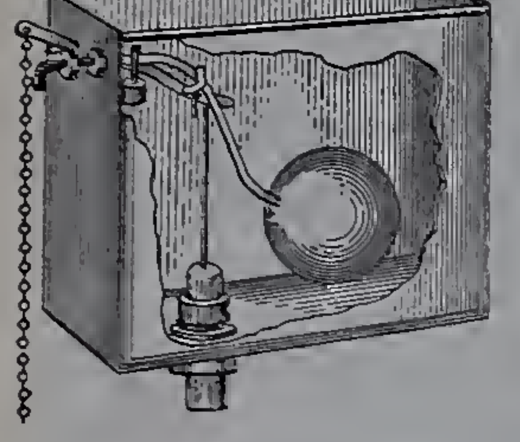


FIG. 327.- Single Valve Cistern.

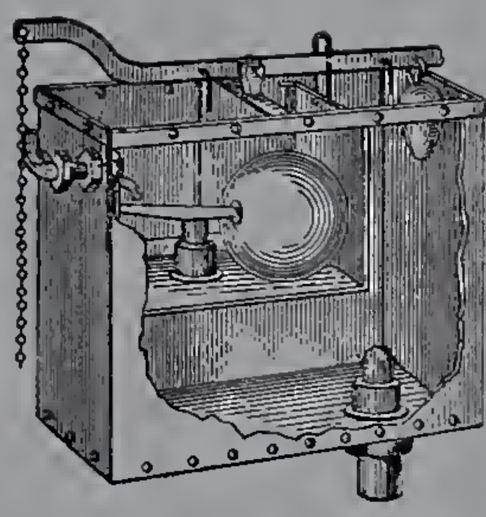


FIG. 328.—Double Valve Cistern.

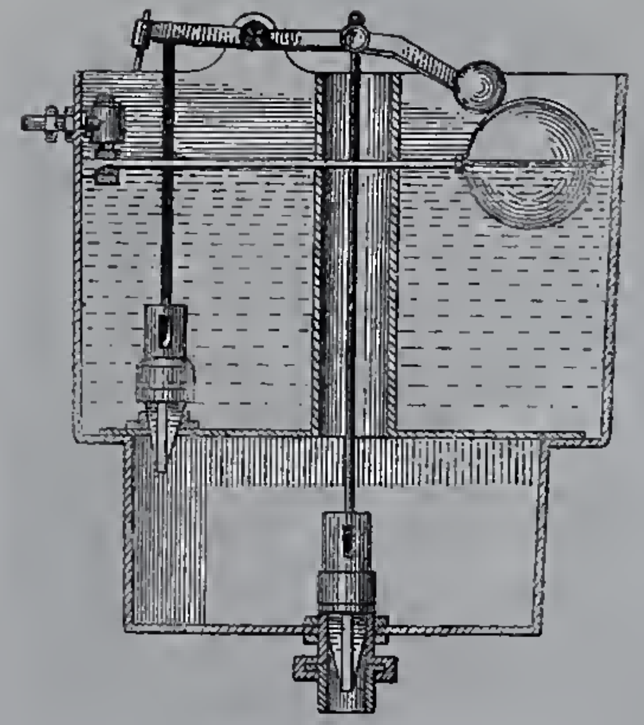


FIG. 329.—Double Valve Cistern with Special Flush-box.

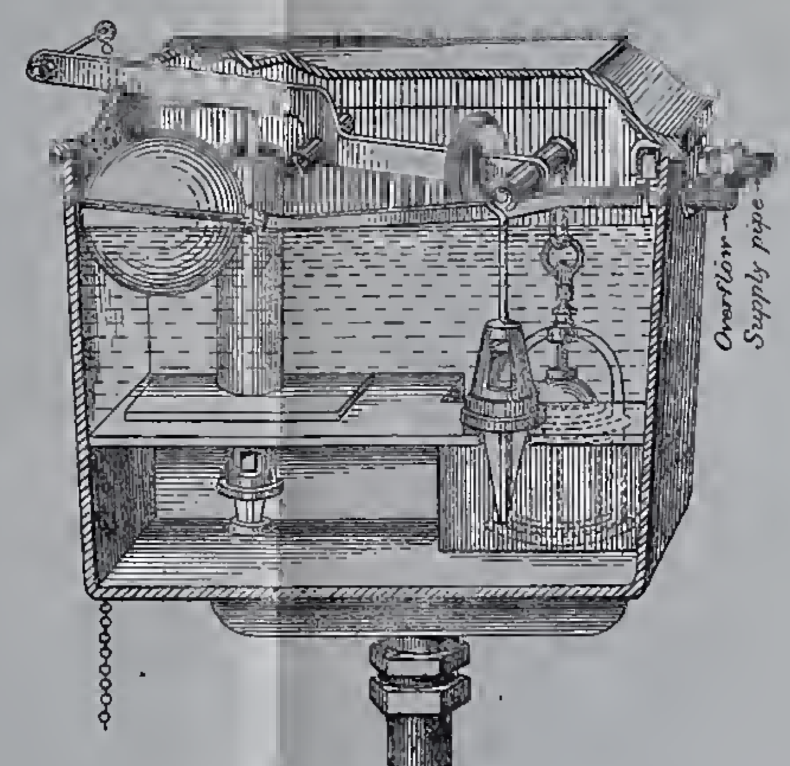


FIG. 330.—The After Flush Cistern.

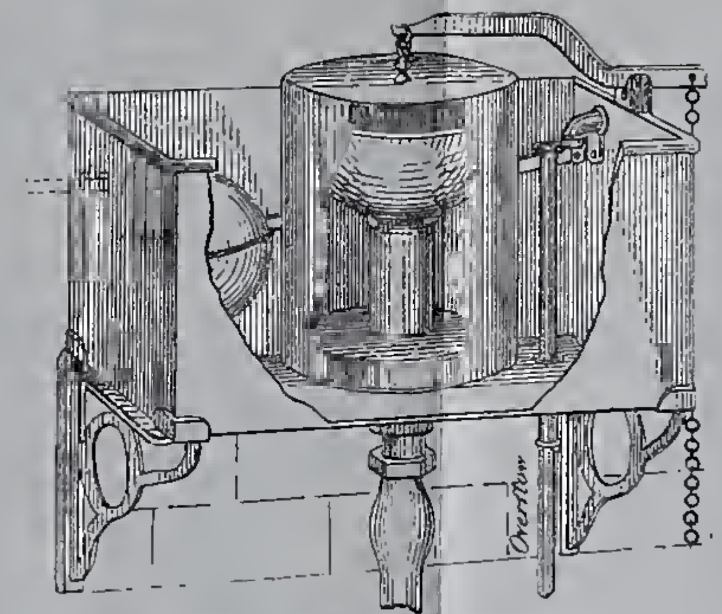


FIG. 331.—Doulton's Vacuum Water Waste Preventer

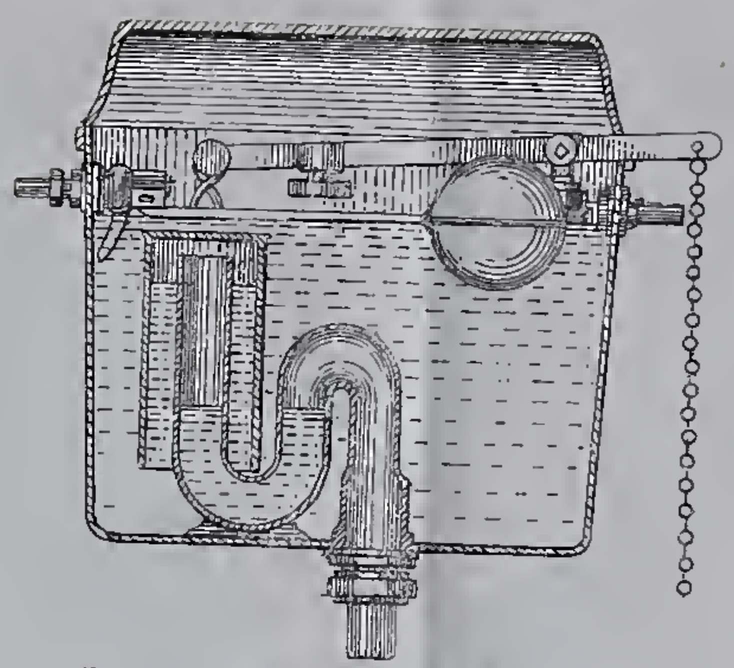


FIG. 332.—Winn's "Acme" Syphon Cistern.

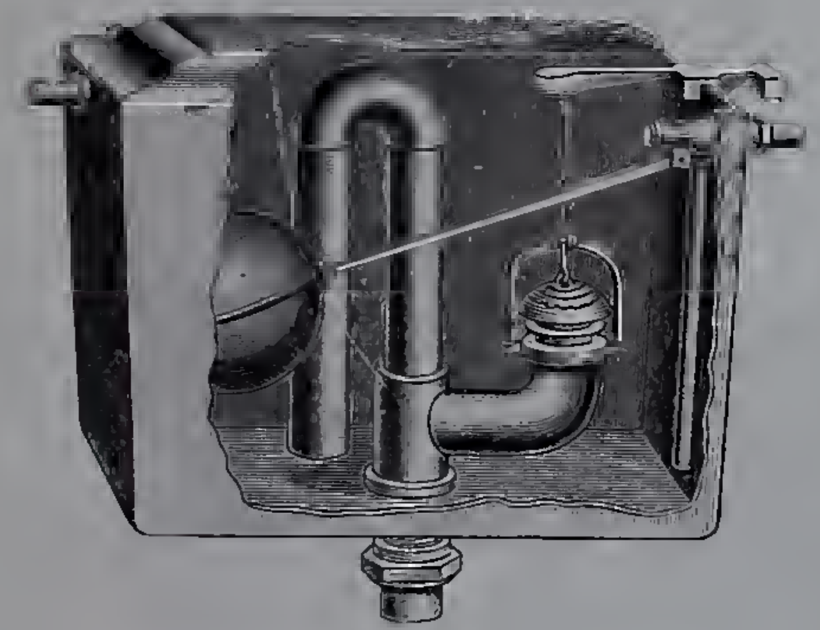


FIG. 333.—Crapper's Syphon Cistern.

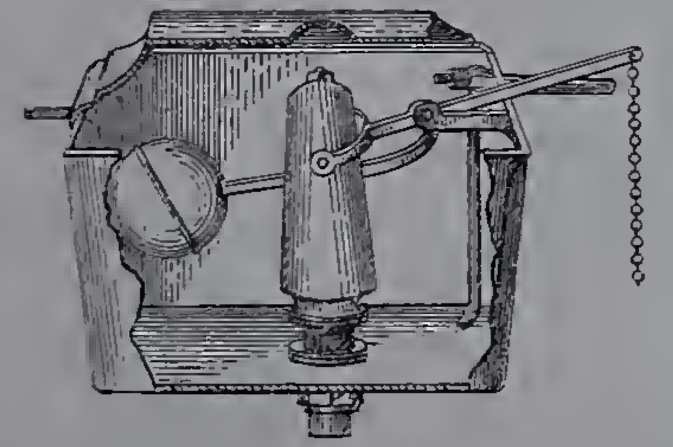


FIG. 334.—Twyford's "National" Syphon Cistern.

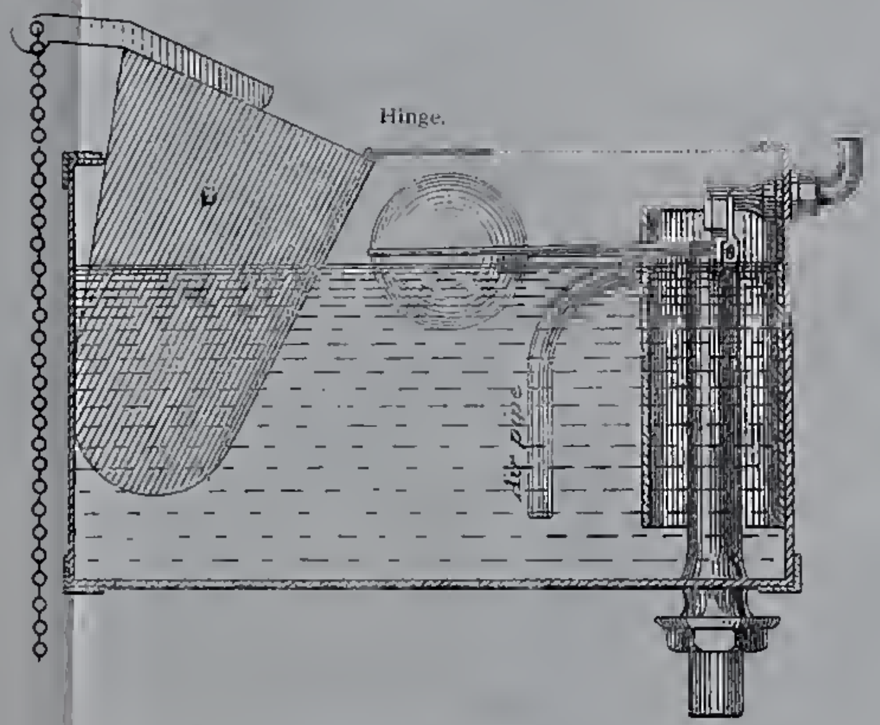


FIG. 335.—The "Westminster" Water Waste Preventer.

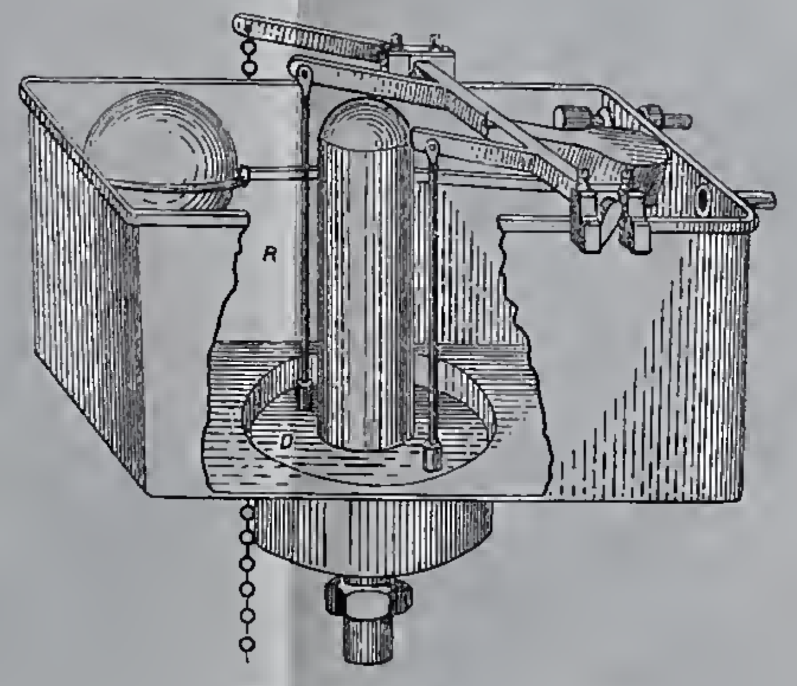


FIG. 336.- Shanks' Valveless Syphon Cistern.

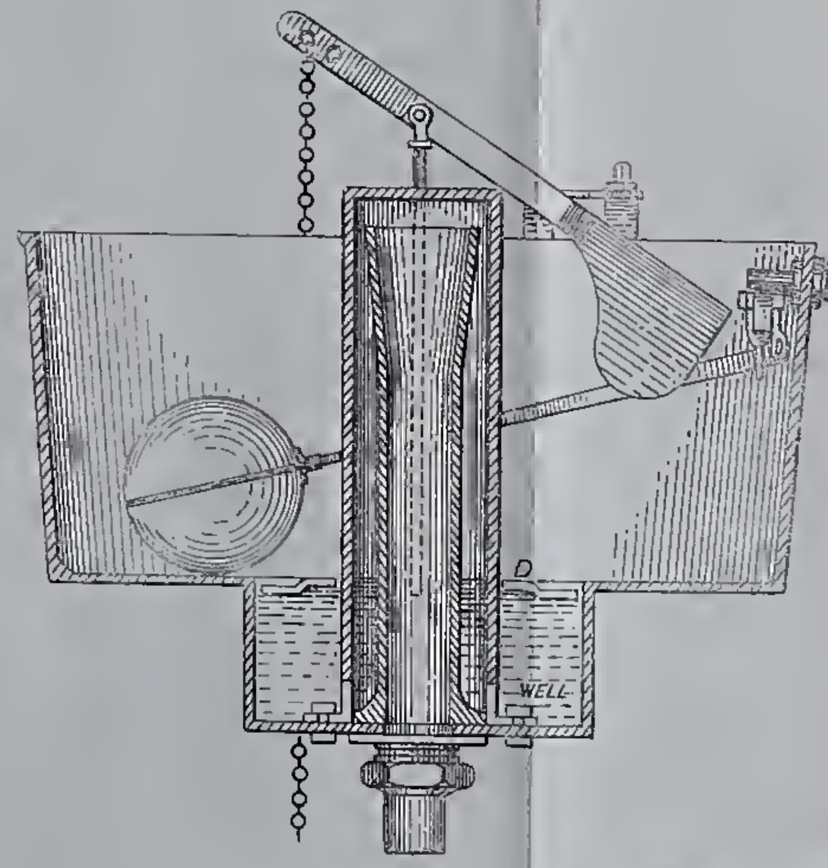


FIG. 337.—Section of Shanks' Valveless Syphon Cistern.

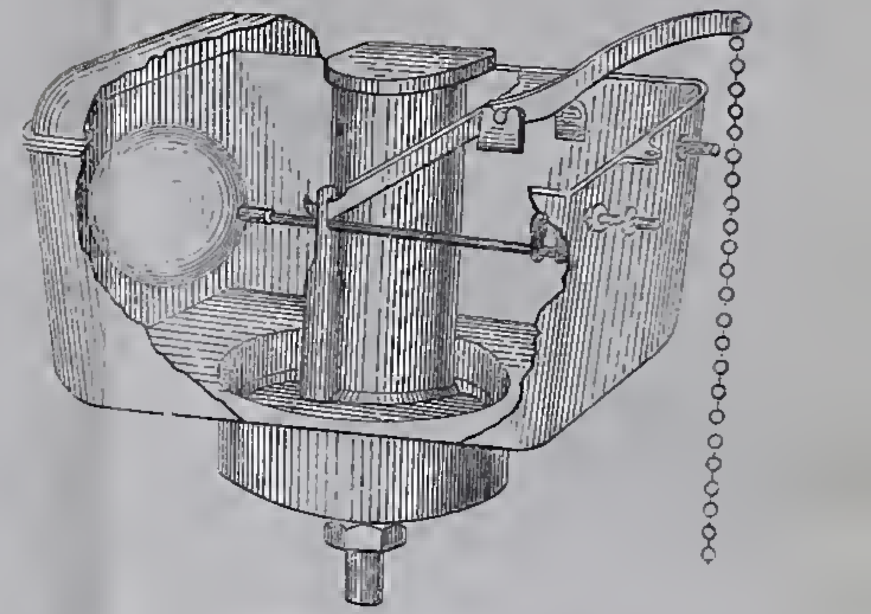


FIG. 338.—The "Reliable Improved" Syphon Cistern.

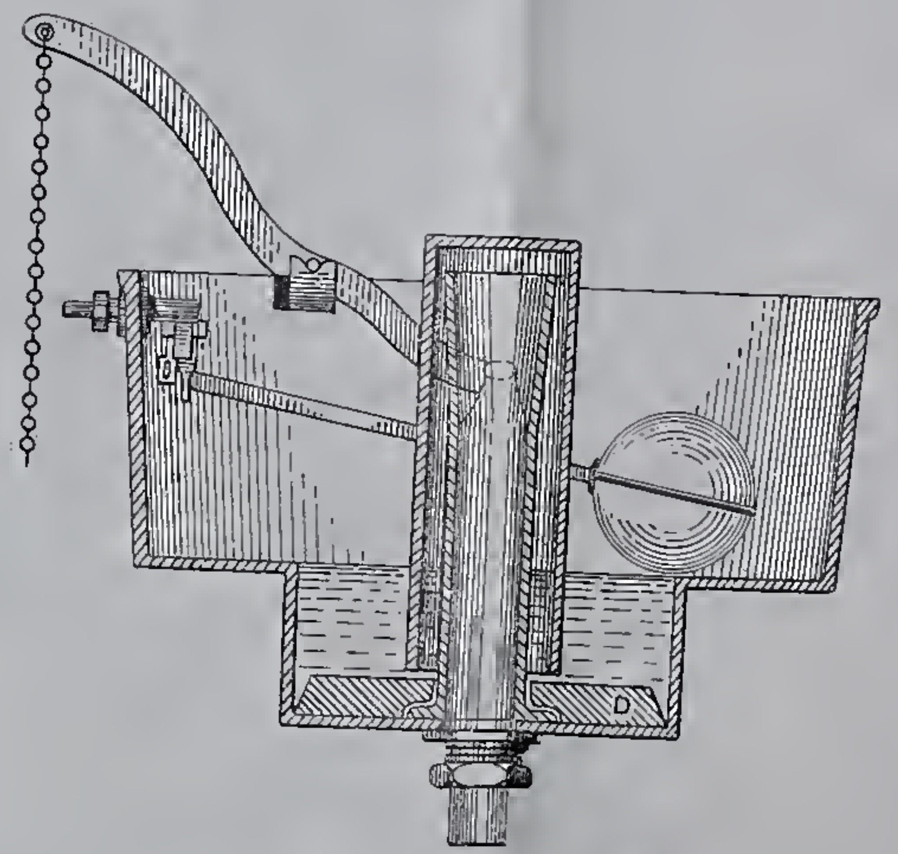


FIG. 339.- Section of the "Reliable Improved."

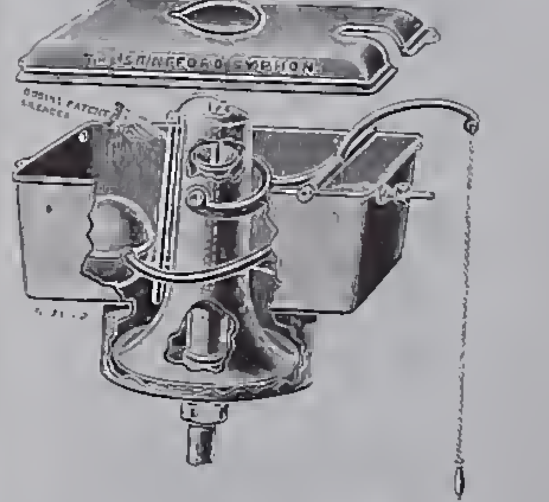


FIG. 340.—The "Stafford" Flushing Syphon.

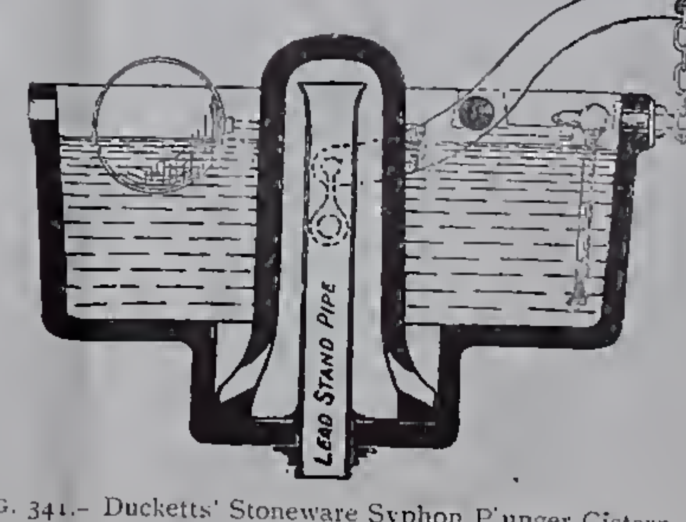


FIG. 341.- Ducketts' Stoneware Syphon Plunger Cistern.

To face page 332.

Tylor's Waste Preventer (Fig. 342) consists of a plunger, C, fitted with washer valve, H, at the bottom, and moving up and down in a metal or elastic socket, E, which forms a carrier, and is fixed to a spindle connected to the lifting lever, F. This valve is made, when

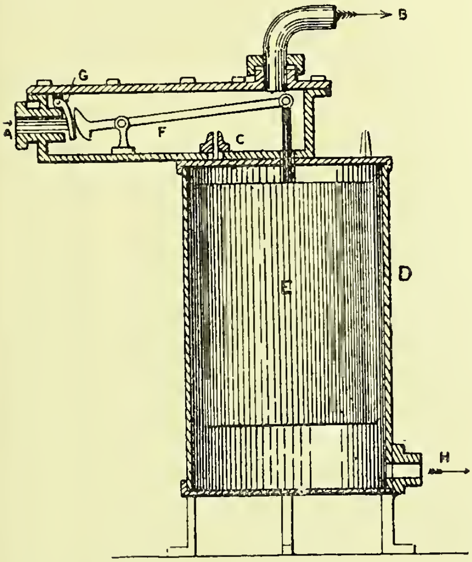


Fig. 343.—Underhay's Water Waste Preventer.

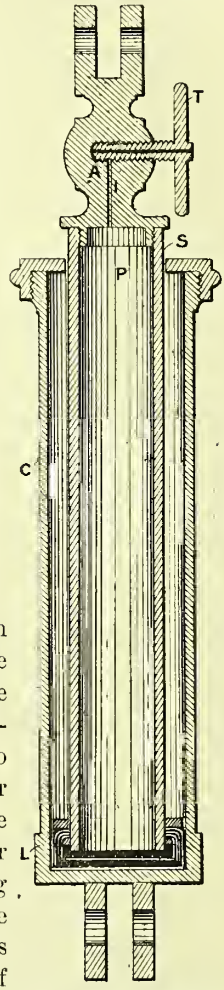


Fig. 344.—Oil Brass Closet Regulator.

preferred, with a flat elastic washer or diaphragm instead of the metal socket, E. K is a ring valve for the purpose of controlling the descent of the metal or elastic socket, E. On the right is a passage-way, L, by which the water flows from under to above the ring valve, K, and is partially opened or shut by turning the tap, A. When the handle of the closet is pulled up, the lever, F, raises the metal or elastic socket, E, which lifts by suction the ring valve, K, and the plunger, C, and thus opens the passage for water through D. When the handle is dropped the lever, F, commences to fall, the speed of its descent being regulated by the quantity of water which is allowed to pass through the passage-way, L. If the closet lever, F, is held up, the metal or elastic socket, E, and ring valve, K, will be kept up too, but the plunger, C, will be taken down on its seat, D, partly by its gravity, but principally by the pressure of the water. The adhesion, or attraction, should cease, and the plunger, C, begin to fall, when the pressure is made equal inside and outside the socket.

Underhay's Water Waste Preventer (Fig. 343) is of a somewhat different class to the flushing apparatus made by Doulton, Jennings, etc. It is fitted to the ordinary supply pipe of the closet, and consists of one cylinder within another. When the plug is pulled the water is turned on by the ordinary valve, enters the "preventer" at A, and commences to flow out into the closet basin at B. But a certain quantity also rushes through C into the cylinder, D, raising the float or hollow cylinder, E, and lever, F. The valve, G, is thus closed (by the cam-shaped end of lever, F), and the water is in a few seconds automatically shut off. Then the water which has entered D also flows off through H, E and F fall, G is re-opened, and the apparatus is ready for another discharge. The effect is practically to prevent more than a certain necessary quantity of water to be used at each flush. The apparatus is usually placed beneath the seat of the closet.

Oil Brass Closet Regulators (Fig. 344) are much used in connection with closets. Such regulators consist of a piston, P, in the shape of a hollow cylinder working within a cylindrical case, C. There is a leather cup, L, at the lower extremity of the piston cylinder, which dips, when at rest, into some lubricating fluid at the bottom of the casing.

When the handle is raised air enters through the annular space, S, at the top of the outer casing, and passes by the cup leather, L.

When the reverse movement takes place, the air inside the cylinders is retained by the cup leather, and can only escape by the tap, T, at the top, so that the descent can be regulated by tightening or releasing the tap, thus partly closing or opening the air passage, A.

The efficiency of these regulators depends thus very much on the cup leather and lubricant ; the latter is liable to get clogged, and then the regulator ceases to act properly.

CHAPTER X.

APPARATUS—*continued.*

Urinals, Lavatory Fitments, Etc.

Urinals.—The provision of urinals for general purposes and especially inside domestic buildings, so as to remain permanently hygienic after use, is one of the most difficult problems in connection with sanitation. This results from the composition of the urine, which consists of uric acid, urea, and other substances, both organic and inorganic, in combination with water, some of the constituents being only slightly soluble.

During the rapid decomposition of urea, which begins as soon as deposited, especially in warm weather or under the influence of any heat from the building, large quantities of ammonia are given off, causing the unpleasant smell so often noticed in rooms devoted to this purpose. Uric acid has a tendency to attach itself to any surface it comes in contact with, where it becomes decomposed, and the corrosion spreading, soon becomes still more offensive. In order to check this tendency, it should be well diluted with water as soon as possible before passing into the waste or drain-pipes, and it is also desirable to use Sanitas, Izal, or some equally efficient disinfectant, to prevent the usual unpleasant odours from being given off.

Urinals should be well lighted and ventilated ; the floors and walls immediately in connection with the urinals should be smooth and composed of non-absorbent material. The amount of surface to be soiled should be as small as possible, and entirely free from any angles or corners which would tend to retain deposits of urine or dirt.

The whole of the possibly soiled surface should be self-cleansing, perfectly smooth, impervious, and not readily acted on by uric or other acids.

A satisfactory flush of water should be provided for the efficient and regular removal of all traces of urine as soon as possible after use.

Three Classes.—Urinals are capable of division into three classes, viz. :—I. Stall ; II. Trough ; III. Basin.

I. Urinal stalls are made with backs and divisions going down to the floor line, of slate, enamelled slate, or painted cast iron (*vide* Figs. 345 and 346). At one time aprons of the same material were added, but are now generally omitted, as they only add to the area to be fouled without any corresponding advantage.

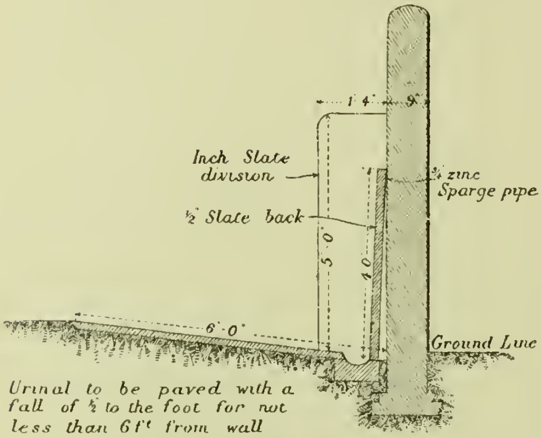


Fig. 345.—Section of Stall Urinal.

The lower part of the apron and sides of the divisions get fouled without a chance of the urine being washed off them, as the perforated supply pipe only sends little channels of

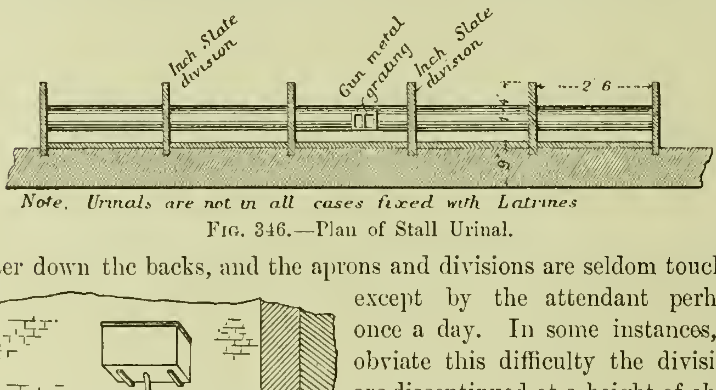


Fig. 346.—Plan of Stall Urinal.

water down the backs, and the aprons and divisions are seldom touched except by the attendant perhaps once a day. In some instances, to obviate this difficulty the divisions are discontinued at a height of about 18 inches above the floor line (see Fig. 347), and the aprons also are omitted; this has the additional advantage of facilitating the cleansing of the urinal.

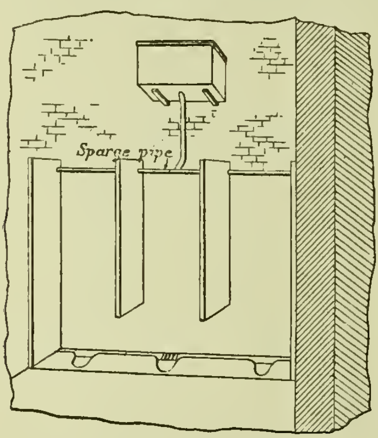


Fig. 347.—Stall Urinal.

Water is kept constantly flowing over the backs of the stalls, either by a perforated pipe, or spreader. The perforated pipe, also called a sparge pipe, should be of brass, copper, or zinc to prevent corrosion. The floor has a fall toward the slate back of half an inch to the foot, and a gutter is formed along the whole length of the stalls at the foot of the wall. The liquid discharges along this channel through a brass or gun-metal grating into a syphon trap.

An improved form, circular in plan, is shown in Figs. 348 and 349, the objectionable corners are got rid of, and the difficulty of keeping it clean is therefore much reduced.

A great improvement on this plan is to replace the gutter by a trough at the ground level, which should be kept constantly full of water and occasionally flushed.

A very good composition with which to treat slate urinals is a mixture of common coal tar and naphtha. It gives a clean and polished appearance to the place, and is at the same time a good deodorant; the dark colour is the only objection to its use.

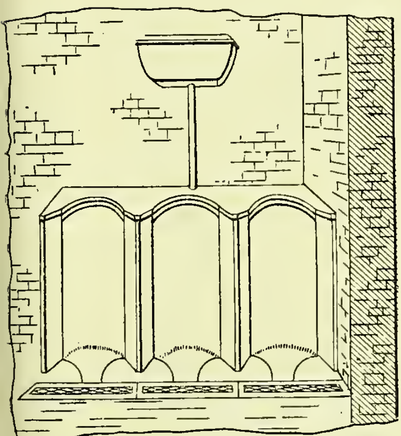


Fig. 348.—Front View.

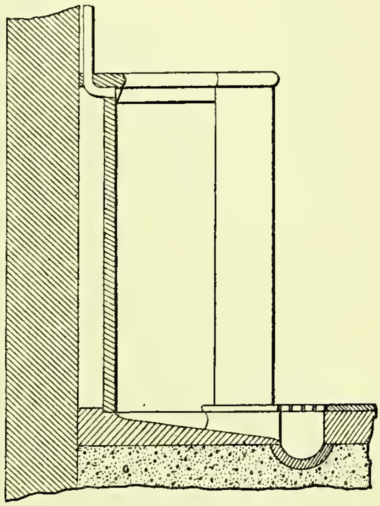


Fig. 349.—Section.

Arrangements should be made to thoroughly wash urinals out once or twice a day, so as to keep every part scrupulously clean.

II. **Trough Urinals.**—From what has been said it would appear that urinals constructed with basins or troughs to contain water, and through which a constant flow is maintained, are preferable to the flush-down systems.

The usual allowance of water for each stall in a public urinal is half a gallon per minute; the quantity of water to be thus dealt with is small.

The diameter of the waste pipes from urinals should, therefore, not be greater than can be well flushed with the ordinary discharge: that is, for stalls, 1½ to 2 inches, and for ranges, 3 or 4 inches, depending on the extent of the accommodation.

Urinals erected in streets are either circular or rectangular in plan, and are preferably made of iron.

Doulton's Flush-down.—Plate XXII. is based on this principle, and is used in many towns. It is given to show a type of public urinal which has much to commend it, and is known as the Lambeth "flush-down" urinal. It is fitted with Doulton's patent automatic flush tank, on Rogers Field's principle.

This urinal appears to be particularly adapted for public use, as it requires but little attention. The trough, capping, and gutter are made of strong, salt-glazed stoneware, so that a perfectly smooth and impervious material is obtained, and thus the common defects in existing urinals of

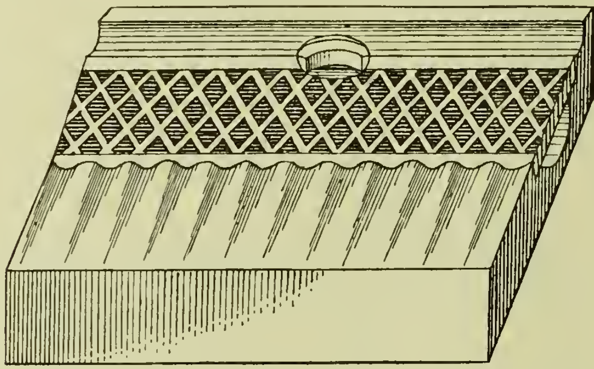


Fig. 350.—Continuous Channel Block, with Fluted Tread, and Hole to receive Waste Pipe, with or without Galvanised Grating.

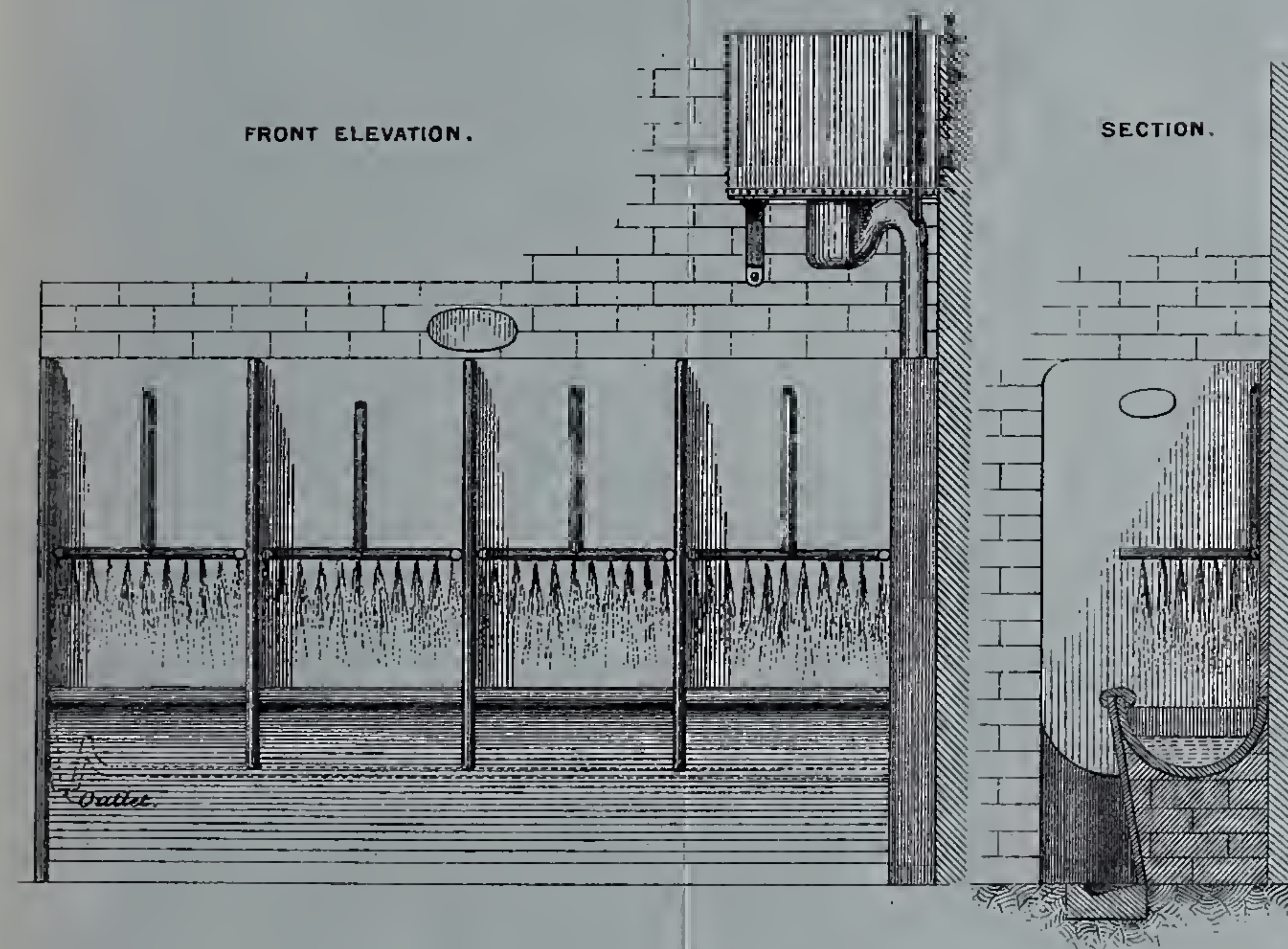
coating and corrosion, which are the chief causes of the offensive smell, are entirely obviated.

At the outlet a weir is formed for the purpose of retaining sufficient water to dilute the urine, and at stated periods (regulated according to the probable number using the urinal) the whole is swept out by the discharge of the automatic flush tank.

The stoneware gutter is formed with a fall to the front, and may be kept clean by means of a branch from the pipe from automatic tank. The backs and apron pieces are made of slate (plain or enamelled), and the latter are sloped inwards to allow room for the feet, and to permit of any drip falling direct into the gutter. The divisions are also of slate, and are raised 18 inches above the floor level, giving free passage for the atmosphere and great facilities for cleansing. Copper flushing pipes, as shown, can be fixed if desired.

Plate XXII.

DOULTON'S FLUSH DOWN URINAL.



J Akerman, Photo lith London

Twyford's Flush-out Trough Urinal (Plate XXIII., page 340) is much on the same principle as that of Messrs. Doulton's, but omitting the sparge pipe.

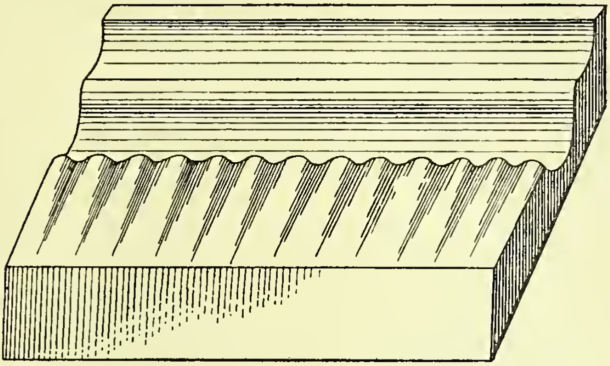


Fig. 351.—Continuous Channel Block, with Fluted Tread.

Automatic flushing is also effected in urinals by Field's flushing tank. The great advantage of such an accessory is that it obviates to a great extent the necessity for an attendant. On the other hand, they are liable to get out of order, unless properly covered and protected.

The continuous channel block used with this urinal is shown in Figs. 350—352.

III. **Interior Urinals.**—Urinals inside buildings are very objectionable, from a sanitary point of view, as it is difficult to prevent their becoming offensive and giving a great deal of trouble. When required in such situations, Class III. description, provided a good type of basin is chosen, with a properly constructed footplate or base (Figs. 353—357) underneath, should be employed. The floor of the urinal or footplate should be dished to proper falls. A great variety of urinal basins, made of white glazed porcelain, are used inside buildings. They are made by Messrs. Beck & Co., Messrs. Doulton & Co., Mr. G. Jennings, and others.

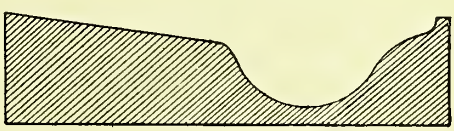


Fig. 352.—Section of Channel Block shown in Fig. 351.

It is advisable to use small urinal basins so constructed that the whole of the interior may be washed over with water every time they are used. The front edge should be as narrow as possible, and bevelled so that droppings, instead of lodging on it, may drain readily into the basin; it should be furnished with a flushing rim.

Conflicting opinions exist as to the form the front of a urinal basin should take, hence the variety of shapes.

In the **Jennings'** pattern the front is generally lipped, as shown in Fig. 356, and this shape is now generally preferred to the plain round front.

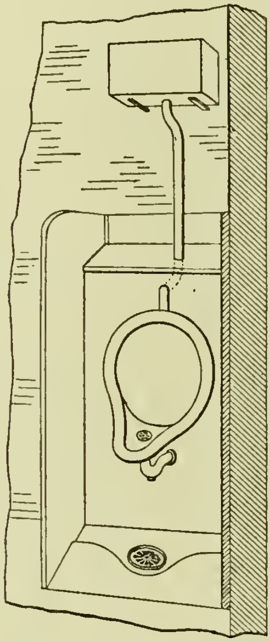


Fig. 353.—Front View of Basin Urinal.

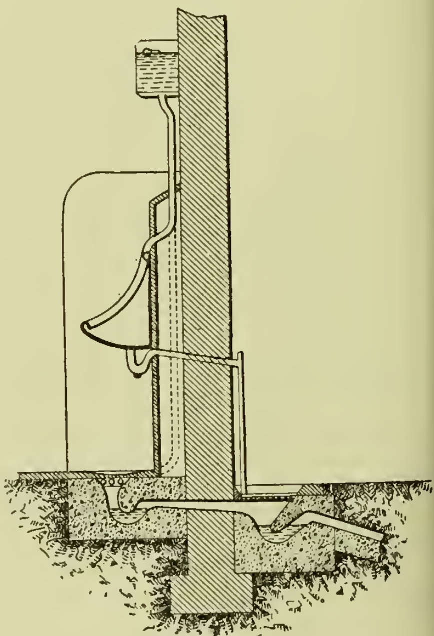


Fig. 354.—Section.

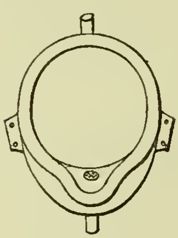


Fig. 355.

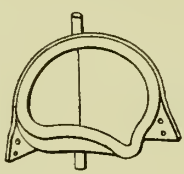


Fig. 356.

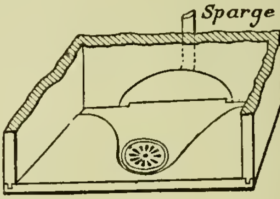


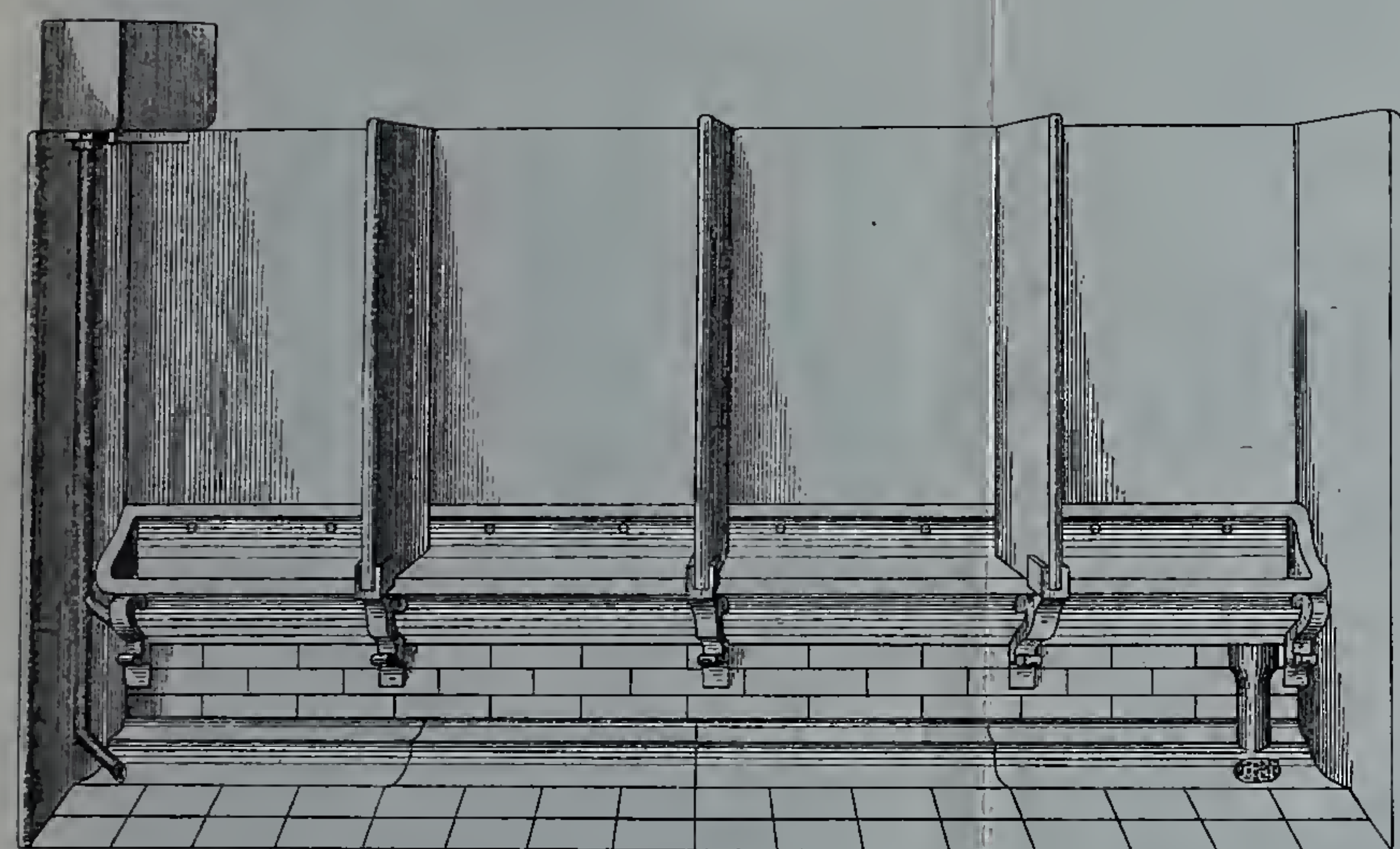
Fig. 357.

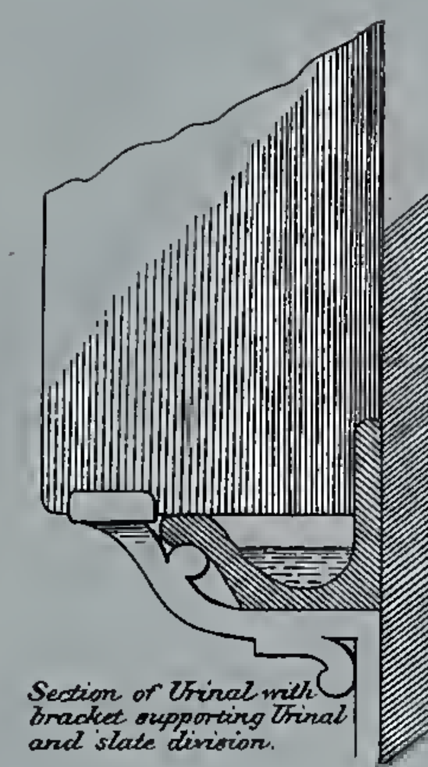
Such basins can be obtained with either flat or angular backs to suit the position in which they are to be fixed.

The advantage of using a basin in place of a stall or trough urinal is that the surface to be soiled is very much reduced in extent, the discharge being confined to one spot, instead of being spread over the floor and walls of the compartment.

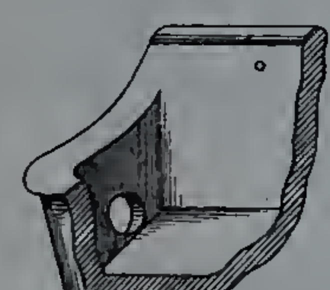
TROUGH (TWYFORD) URINAL.

PLATE XXIII.

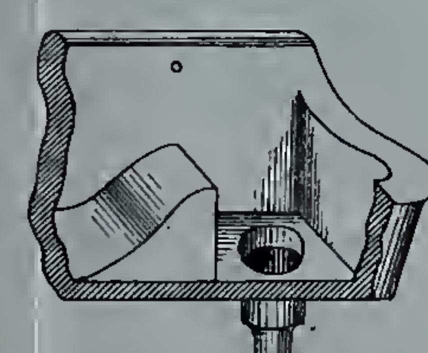




Section of Urinal with bracket supporting Urinal and slate division.



Section of inlet end.



Section of outlet end.

J Akerman, Photo-lith London.

Hellyer's.—In the Hellyer pattern it is "wide fronted" (Fig. 358).

Each is designed to prevent any droppings which may fall on the outside of the basin from running down on its outer side. The front of the basins are undercut, or throated, to cause them to drop on to the floor, which should, of course, be constructed of tiles, or other impervious substance.

The "Holborn" Trapped Urinal.—The "Holborn" trapped urinal

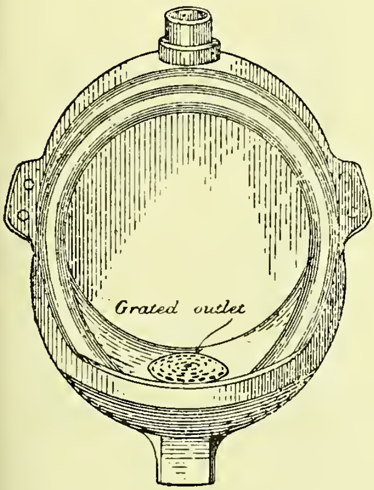


Fig. 358.—Hellyer's Basin Urinal.

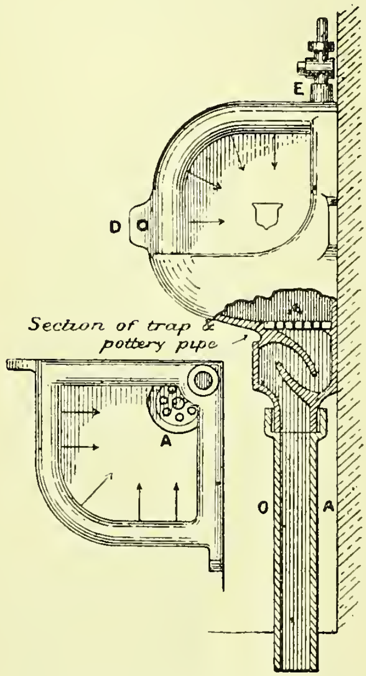


Fig. 359.—The "Holborn" Trapped Urinal.

(Fig. 359) combines a urinal and trap in one piece of white, glazed earthenware.

In order to render the trap easily accessible, the grating, A, is made to lock down by means of a key, which also unlocks the inspection door in front of the trap.

This urinal is secured by screws through lugs in the wall. The water enters by the boss, E, at the top, and flushes the entire surface of the pan, as shown by the arrows in illustration.

Tylor's Patent Urinal Basin (Figs. 360, 361).—The part through which the discharge takes place is at a higher level than the bottom of the basin, thus retaining sufficient water in the basin to cover the bottom—about two inches in depth.

It is best, however, in all urinals, to discharge through a proper grating and trap at the floor level, so that the urinal waste may be entirely disconnected from the drain, and at the same time easily accessible for examination and cleansing. This rather points to the use of a straight delivery, with a constant flow ; but as the quantity of water allowed by most water companies is very small, it is better economised by flushing automatically at intervals, and then the basin should hold a small amount of water. Plate XXIV. shows a range of Twyford's urinals suitable for a large establishment.

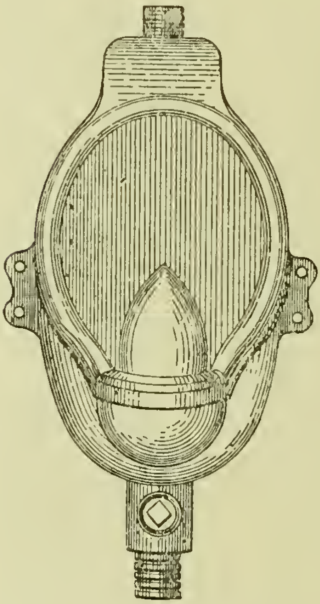


Fig. 360.—Tylor's Urinal Basin.

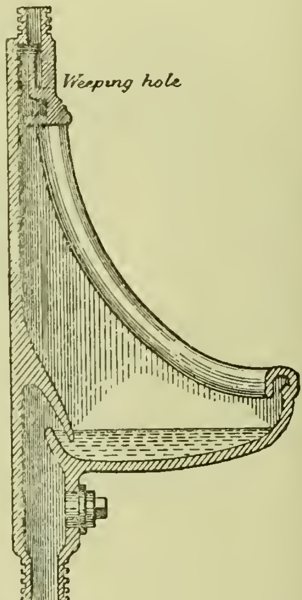


Fig. 361.—Section of Tylor's Urinal Basin.

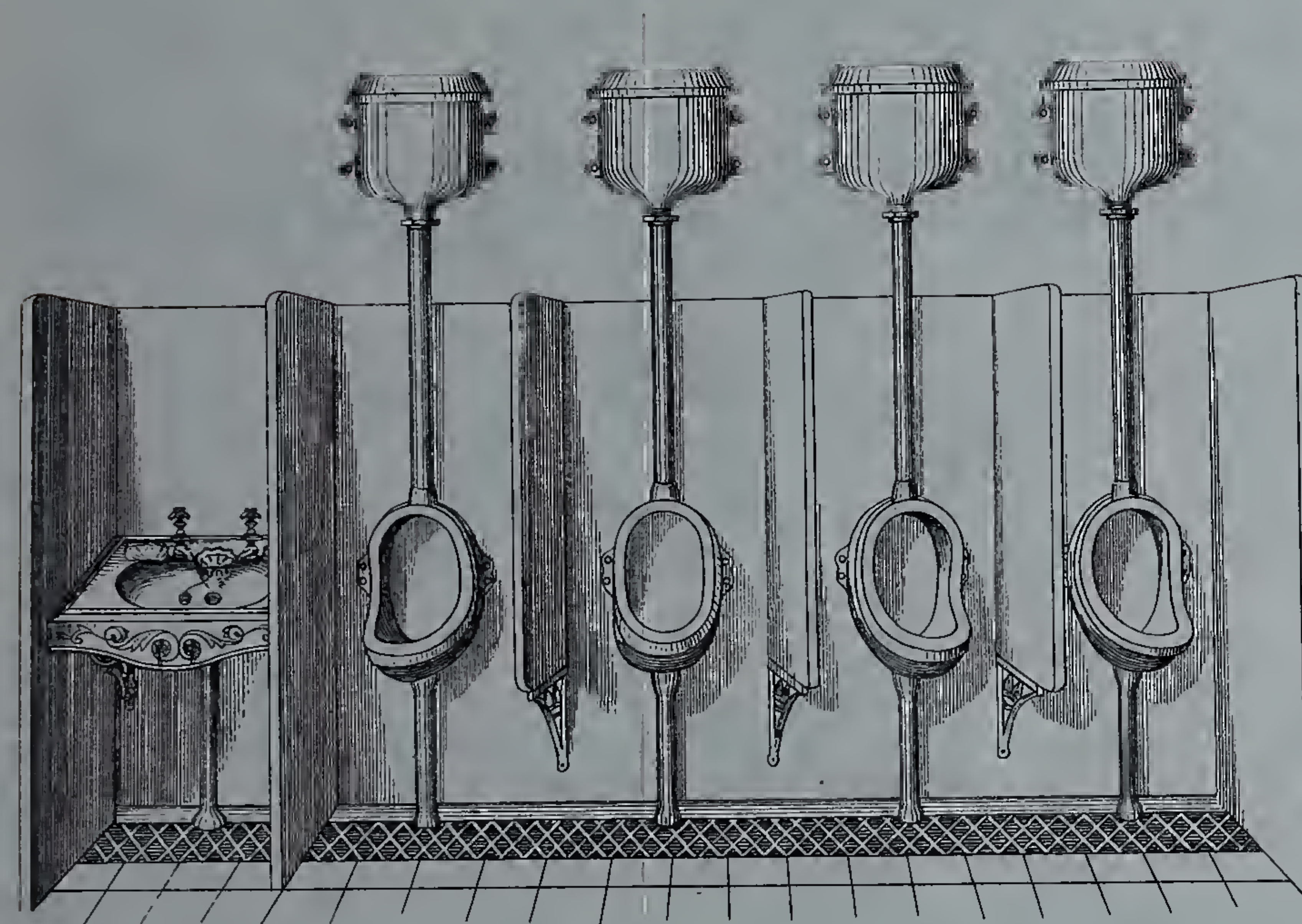
Public Conveniences: Underground.—The following description of a few samples of such works, etc., as well as the illustrations, have been furnished by Mr. G. Jennings :—

"In Figs. 1 and 2, Plate XXV., are given detailed plans of an underground convenience with separate compartments for men and women, this convenience being situated in the middle of a wide thoroughfare in London.

"Fig. 1, Plate XXV., is the plan at road level, showing, by the kerbs and guard-posts, that it forms a refuge or 'island' near a crossing. Inside the guard-posts the surface is nearly wholly composed of prism lights, affording a particularly bright interior below in this case. This

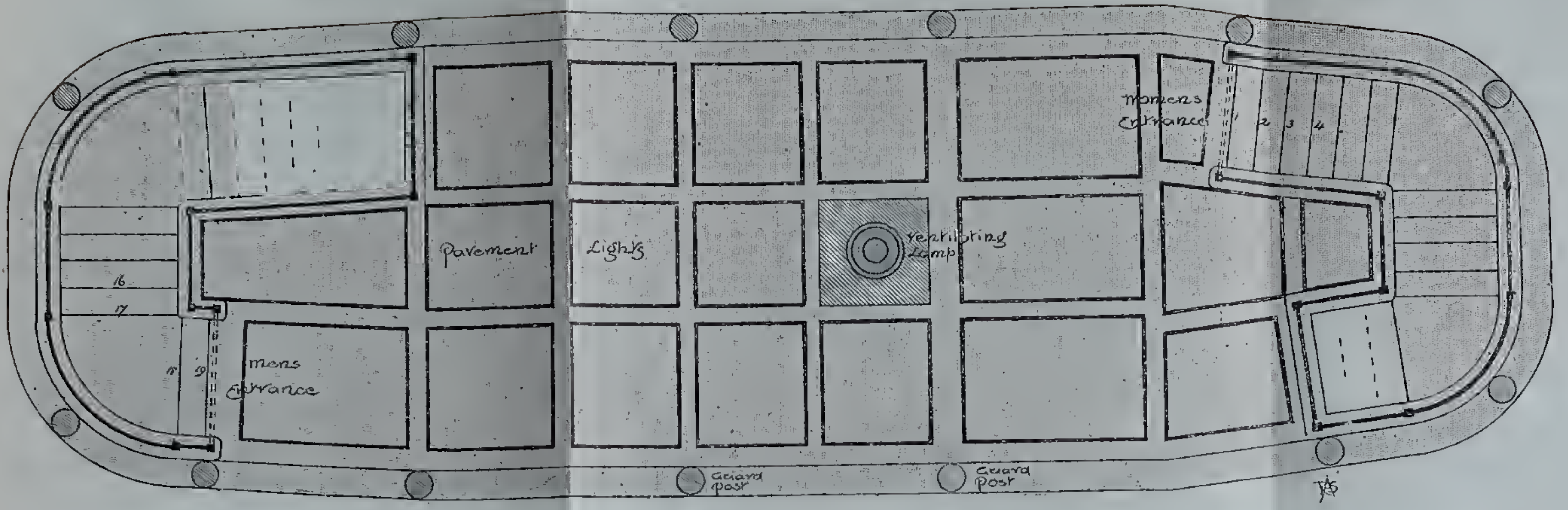
Plate XXIV.

URINAL, (TWYFORD) BASIN RANGE.

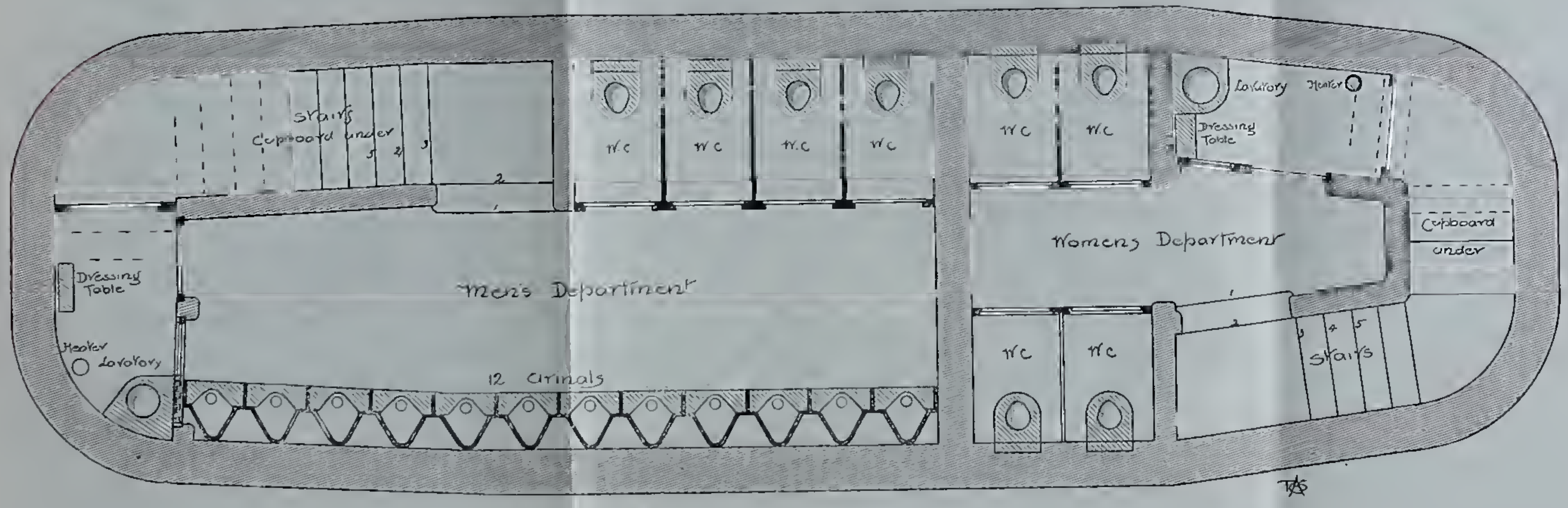


J. Akerman, Photo lith. London.

UNDERGROUND CONVENIENCES.—PLANS.



Plan at Road level



Plan below Pavement

To face page 342.

is a detail that is sometimes sacrificed to a greater extent than it need be, with the consequence that the lighting by gas is indifferent compared to daylight, and the cost of maintenance is very greatly increased, sufficient in some cases to incur a loss where a profit would otherwise have been experienced. The gas also discolours the decoration of the cement and ironwork, and adds to the warmth of the place in summer. Gas or some illuminating agent is, of course, always necessary after dusk, but there is no reason why its use should not be avoided by every possible means during daylight.

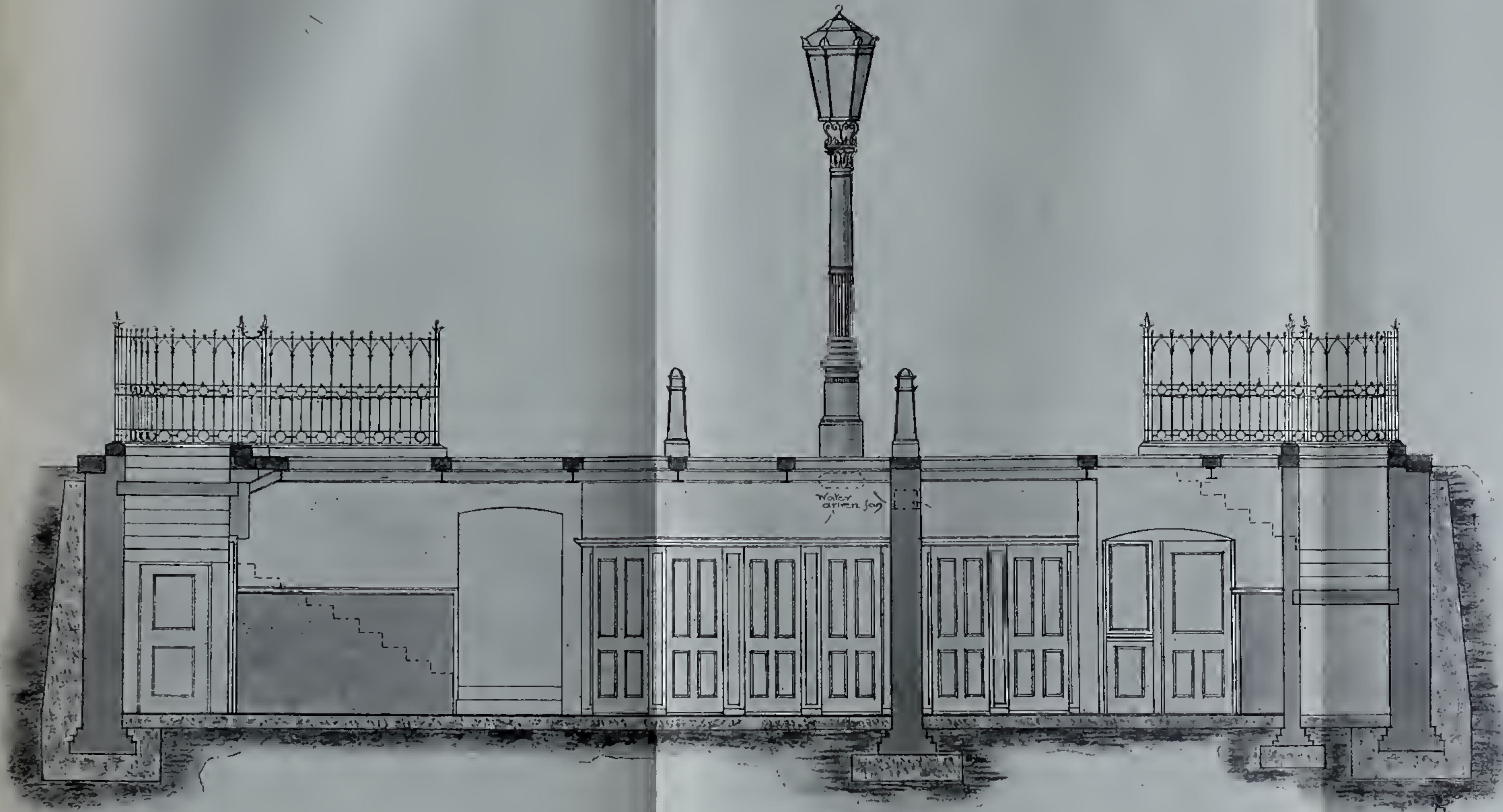
"The inner kerbs of this plan are selected hard York stone, while the outer kerbs are granite. The guard-posts are of iron, and should be preferably of a tapered design, as free from projecting surface ornament as possible. They should be twelve inches square at the base, so that the outer granite kerb, which is usually twelve inches by eight inches, butts against the base of the post, thus saving unnecessary cutting and notching. The position of the ventilating lamp is nearly central, coming over the end of the men's section; but communication is provided, that the adjoining compartment be ventilated, as will be seen by the next illustration. This illustration, it will be noticed, gives the plan of the entrance-ways, with the surrounding railings and screens. Fig. 2, Plate XXV., is a plan of the convenience interior below ground, showing the arrangement of fittings, also the stairs, one staircase acting both for entrance and exit in this case. Where space is limited—and useful space is nearly always limited in these places—the opening beneath the stairs can always be utilised either as the attendant's room, or attendant's stores and lock-up, some such provision being needed for towels, materials, and utensils. In the men's section there are twelve urinals (as described in the specification), four water-closets, and one lavatory basin with dressing-table. The lavatory convenience is very limited in this case, as the neighbourhood is one where this particular accommodation would not be in much demand. The water-closets have marble divisions; the urinals are of the stall design; and enlarged photo details will follow after these example plans. The women's section has four water-closets, also with marble divisions, one lavatory and dressing-table, and attendant's accommodation under stairs. Fig. 1, Plate XXVI., is a longitudinal section of the same convenience taken across the centre, giving an elevation of the side on which the water-closets are situated. This also shows the lower steps and entrance in the men's section, and the upper steps and landing in the women's department. This section gives a good idea of the appearance at ground level, showing detail of the wrought-iron railings around the entrance-ways, the position and appearance of the ventilating lamp column, etc. It will be seen that the base of the lamp comes near to the division wall separating the two compartments, and the extraction of vitiated air from the women's section is provided for by apertures near the top of the division walls. The arrows show the direction of the air passage, and from the next sectional illustration it will be seen that there are three apertures provided. The air propeller or fan is worked by water, as described in specification, and particulars of its construction will follow. In this illustration, and the following, Fig. 2, Plate XXVI., the details of footings and concreting are clearly shown, the latter drawing in particular illustrating how completely surrounded the structure is with concrete, much as if it were built in a concrete tank. Fig. 2, Plate XXVI., gives the elevation of the division wall, showing the ventilating apertures referred to, and their position in relation to the ventilating column. This wall is shown to have a marble dado. The marble divisions of the water-closets and urinals are also shown, and a cross section of one of the syphonic closets. A little further detail of the railings is given, and the kerbs with positions of guard-posts are clear. In this illustration, and the preceding one, the girders supporting the lights at ground level are seen.

"Plate XXVII. gives a view of some urinals, these being Jennings' 'Radial' design. This urinal is of a special design, as being considered good for the purpose in view, very strong, and requiring the least flushing; or it may perhaps be said that it gets the most thorough flushing possible with a given quantity of water. The plan of the design is triangular, with rounded back angle, and tapered down from top to bottom, there being a difference of two and a half inches in the size at these points. The flush of water occurs from the top rim, which is a flushing rim in fact, and the tapered sides ensure all parts getting a share of the down-flowing water, as will be understood. The tapered sides also prevent all liability of splashing, as any little irregularity in the flushing orifices does not necessarily cause the issuing water to fall to the bottom without touching the sides. The liability of having the boots and clothing splashed by the falling water was always, and is, a great source of annoyance with some of the old types of urinals still largely used. What greatly aids in preventing a splashing from the falling water is the form of the lower part of the urinal. This is not flat, but tapers forward from the sides and back, delivering the water to the outlet in a steady stream without distributing particles or splashes on its way.

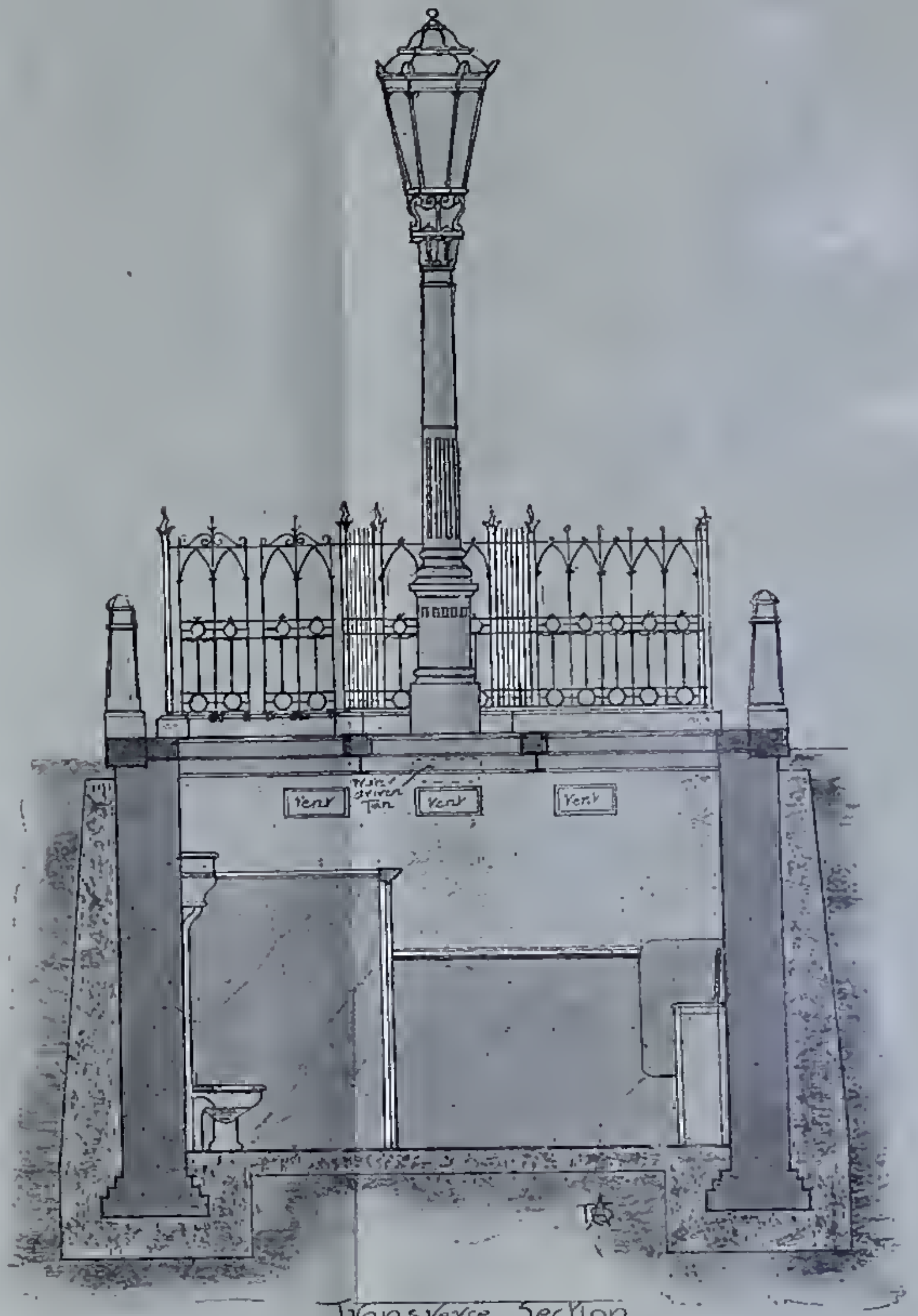
"Earthenware is the material of which these stalls are made, two inches thick, and well glazed on the front. They are far stronger than any of the older types of basins or receptacles, with practically no liability of becoming broken after fixed. The writer has not seen one broken in use yet, the only breakages coming to his knowledge being those that have occurred through ill usage in transit from the potteries. A feature of

UNDERGROUND CONVENIENCES.

Longitudinal and transverse section of a Convenience situated in the centre of a busy London thoroughfare. These two Illustrations, and the Plans shewn on Plate XXV., give all the details that enter into the construction of Modern Works of this kind, suited for Populous Places.

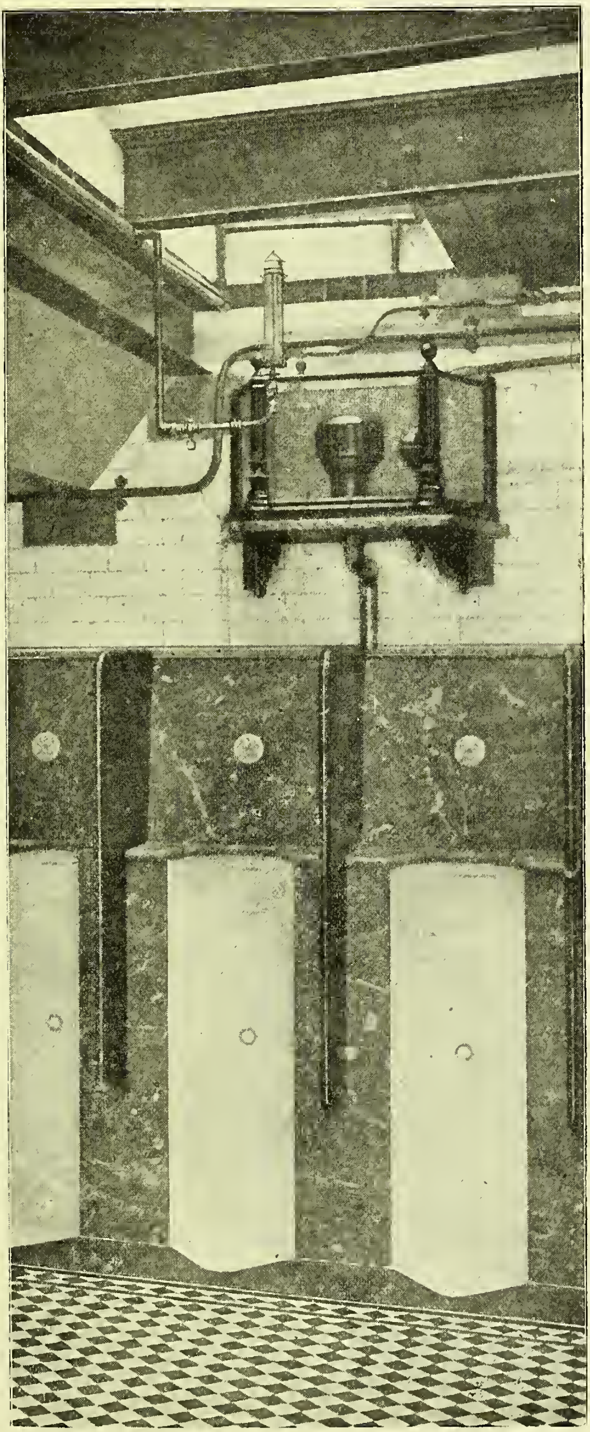


Longitudinal Section



Transverse Section

To face page 344.



UNDERGROUND CONVENIENCE, WITH FLUSHING TANK AND CONNECTIONS.

some importance in the urinals illustrated is the triangular or pointed gap in the slate base plate, where a user's feet come. In the absence of this opening there occurs an untidy and unpleasant wetness where the user stands, but this fault is well overcome by the projecting opening shown.

"A clear view of the flushing tank is had in this illustration. These tanks, of whatever kind that may be used, are automatic in their action, discharging their contents at regular periods, which may be made frequent or otherwise to any reasonable extent, as may be required by the amount of use the place has. There is no exact number of urinals put to one tank, but where convenient a tank to each six is a good arrangement. The automatic action of the tank is brought about by the air, which is locked or held between two syphons, being forced out when the water in the tank rises high enough to exert the pressure necessary, and this sets up the syphonage action which discharges the contents of the tank. Some of these tanks have to rely on a reverse action ball valve to get the syphonic action correctly, while others are made with a small auxiliary syphon which discharges the air when the tank is full enough. It will be noticed that in the majority of these examples the floor is finished with black and white vitreous tiles, and in the writer's opinion nothing can excel these for good service where subject to considerable wear and tear. Their appearance is good, worked alternately as shown, with a border made up of half-tiles and strips. The most suitable kind are those having silica (flint) in their composition, some having quite a noticeable glaze to the material, which adds considerably to their lasting qualities. The size of the tile is best if no larger than two-and-one-eighth inches, as with larger tiles the laying cannot always be so firmly effected. These small tiles are undoubtedly the best, and give the greatest satisfaction in use; nothing can be more lasting, more easily cleaned, or more favourable to keeping clean with a minimum of labour and attention. The walls of conveniences are sometimes tiled, or have occasionally been covered with marble. Instances are also met with of ordinary brick walls cemented over and painted. Almost anything is preferable to the latter, but the best work is done with white glazed bricks as illustrated. Certainly the expense of repairs or decoration is reduced to a minimum, and, as with tiled floors, they are favourable to cleanliness in every way, with the least possible attention. In arranging for brickwork of this kind, however, it is always as well to ascertain the thickness of joint that will be passed by whoever may have the supervision of the work. Under no circumstances are thick joints commendable ; but, on the other hand, joints of an impracticable thinness are sometimes required, which, although possible, render the work difficult and increase expenses without any compensating advantages. In several conveniences recently constructed the walls have been rendered in Portland cement and sand, well roughed, then covered with 'opalite.' This is opal glass, roughed at the back and cut into sizes to resemble glazed brickwork. As yet it is early to give a reliable opinion on this material, but certainly, if any settlement takes place in the brickwork after these glass tiles are fixed, the result must be anything but satisfactory. In the writer's opinion, it is desirable that the brickwork should be allowed to stand, say, two months if possible, before the opalite is fixed. In fact, the whole of the sanitary appliances might well be fixed, and, of course, the structure roofed in and the floors laid, making the opalite linings the last piece of work."

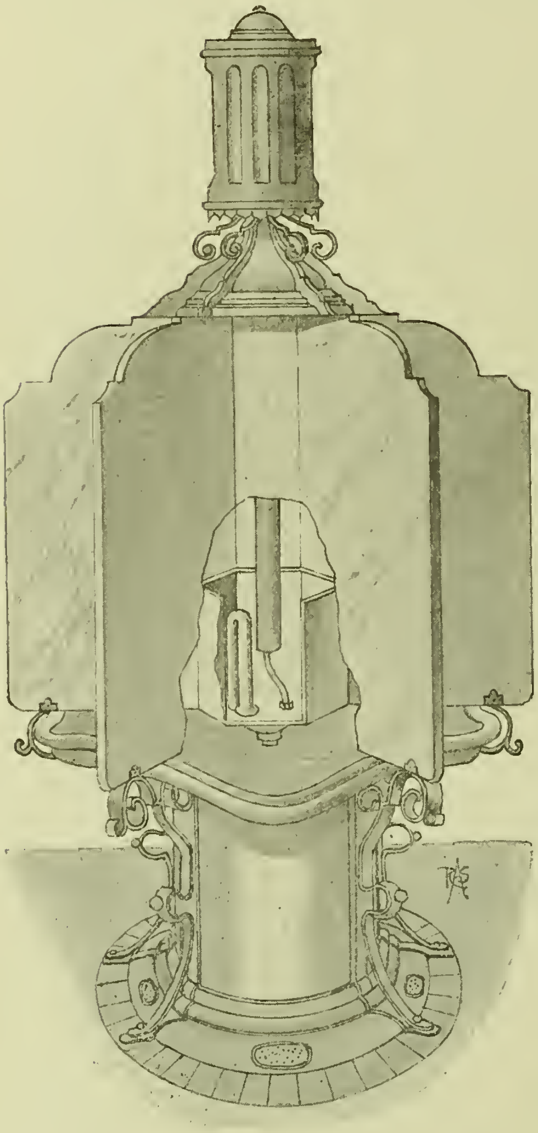


FIG. 362.—Circular Pedestal Urinal.

"Fig. 362 illustrates Bolding's 'Laydas' circular pedestal urinal, to which the syphonic action of discharge is applied, the same as described with the preceding closets, but in this case it is made automatic in its work. The pan is of fire-clay, highly glazed, and provided with a flushing rim, so that besides being self-emptying it is also self-filling and cleansing."

Automatic Flushing Apparatus.—There is a great variety of this apparatus in the market, such as :—

Jennings' Automatic Urinal Flushing Tank.—By the arrangement illustrated (Fig. 363), consisting of a ball valve and syphon, the contents

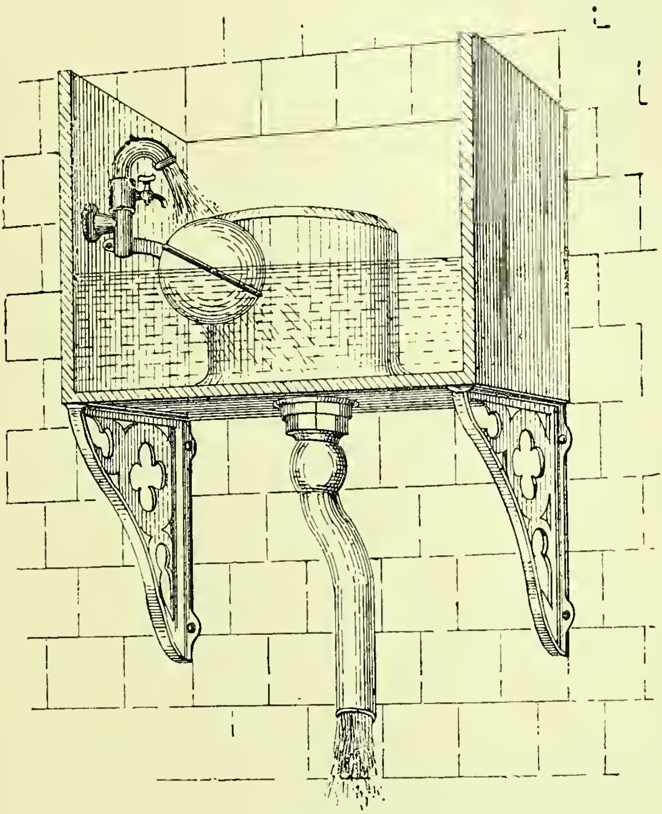


Fig. 363.—Automatic Urinal Flushing Tank.

of the cistern, when full, are discharged with considerable force and velocity, thoroughly flushing any fittings or the line of drain with which it may be connected. The action of the ball valve is the reverse of that which obtains within the ordinary ball-cock, so that the flow is greatest when the ball is at its highest level.

The small-bib cock in the above figure admits of a by-pass for the water when the ball-cock has fallen, and thus gradually restores its action.

The time occupied in filling the tank is effectively controlled by the regulating key, S, on the improved inlet supply valve (Fig. 364), and the periodic discharge of the contents can thereby be determined at will. The cistern in which the syphon is placed is supplied by means of a ball valve, made to open as the water rises in the cistern, the reverse way of the usual action. Thus the water is brought into the cistern with sufficient force to start the syphon.

Fig. 364.—Inlet Supply Valve.

Crapper's Automatic Cistern is illustrated in Fig. 365. It is based on Rogers Field's principle.

Twyford's Automatic Syphon Cistern (Fig. 366) is very similar to the last, but the supply pipe is carried to the bottom. It is used in connection with his trough urinals, etc.

Merrill's Patent Flushing Syphons and Tanks.—The water feeding into the tank rises until it reaches the top of the long leg (Figs. 367 and 368) of syphon, when it runs down into the tipping bucket, which is pivoted beneath, and into which the long leg dips. The water rises in the tipping bucket until it reaches the long leg, the end of which it traps. This slightly compresses the air in the syphon. No more water will now run down the syphon until there is a greater pressure of water in the tank than the pressure of air in the syphon, or in other words until there is a head of water on the syphon. More water is then forced down into the tipper, further filling it and still more compressing the air, necessitating a still further rise in the tank to force more water down the syphon. This goes on until the tank is full. The tipping bucket is also full to its tipping level, when it tips and discharges its contents, unsealing the syphon, which the head of water in the tank instantaneously charges.

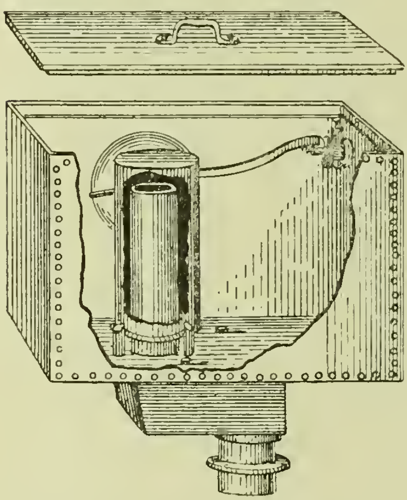


Fig. 365.—Crapper's Automatic Cistern.

Slop Sinks.—Slop sinks have been constructed to prevent as much as possible the carriage of foul water about a house, and to thus economize labour.

For this purpose they are generally placed on an upper, or bedroom floor, but should be fixed in a chamber cut off from the bedrooms by means of a corridor or passage in the same way as recommended for water-closets.

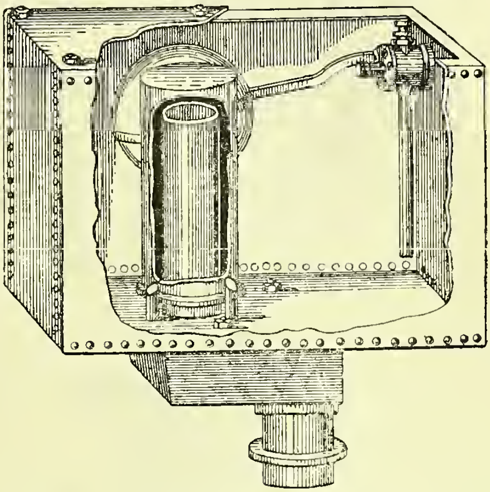


FIG. 366.—Twyford's Automatic Syphon Cistern.

It is most essential that every portion of a slop sink within a house should admit of easy access and inspection, and also that the flushing should be good, otherwise these so-called conveniences become a nuisance of the worst type.

The conditions of a good slop sink should be chiefly those for a good *flush-down* water-closet, including outside soil-pipes, ventilation and trapping ; the shape should be such as to prevent splashing. There should neither be valves nor other working parts, but simply a basin with self-cleansing trap above the floor line. A movable screener or grating, of some non-absorbent material, should be fixed in the basin to arrest the passage of flannels, brushes, etc., that might be accidentally thrown in with the slops.

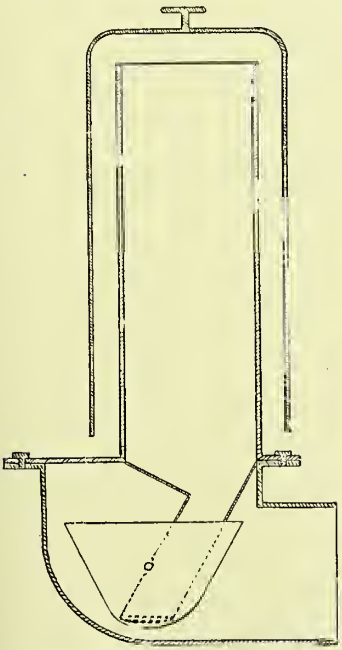


FIG. 367.—Merrill's Flushing Syphon.

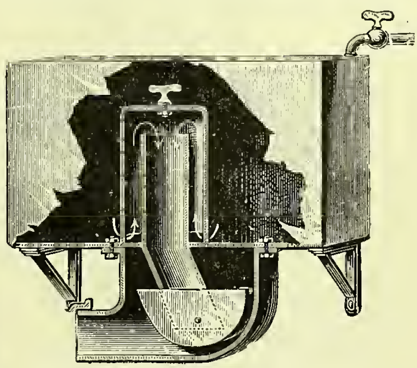


FIG. 368.—Merrill's Flushing Tank.

It is best to have the slop sink trap of cast-iron or lead, in order that a perfect joint may be made with the soil-pipe.

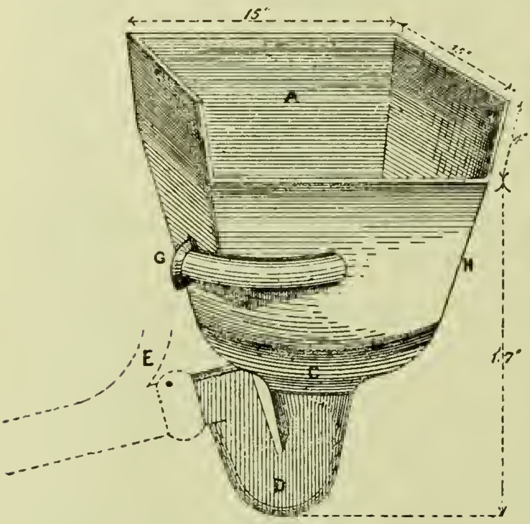


FIG. 369.—The "Water-shoot" Slop Sink.

Therefore, in ordinary houses, it is better not to provide slop sinks, but to use the water-closets for this purpose.

When adopting this arrangement, however, great care should be observed in the description of the w.c. apparatus used. A valve closet is not suited to this purpose, as when slops are thrown into it the level of the liquid in the basin is raised, and the water passes off by the overflow before the handle is lifted to empty the contents, resulting in the overflow trap being filled with foul liquid, which gives off very offensive odours.

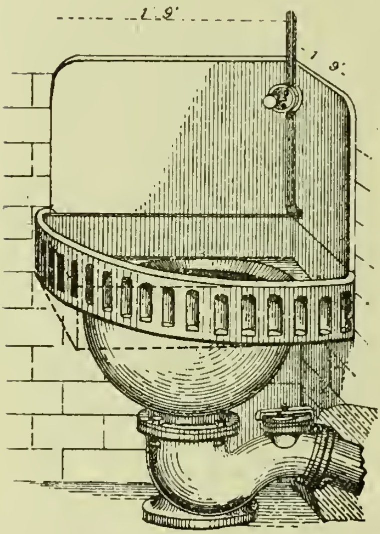


FIG. 370.—Angular Slop Sink.

Dent & Hellyer's Water-shoot.—Fig. 369 is a slop sink known as the "Water-shoot." It is designed by Messrs. Dent & Hellyer, and is made of cast iron, enamelled on the inside, and fitted with a strong, white, glazed stoneware screener. The configuration is such that there is no place of lodgment in any part.

Doulton's Slop Sink. — The next figure (370) represents an angular slop sink by Messrs. Doulton & Co. It consists of a glazed stoneware top with slate skirtings. The basin and syphon are of iron, and it is provided with a flushing valve by which the basin is cleansed after use.

Tylor & Sons' Slop Sink.—A slop sink, by Messrs. Tylor & Sons, is shown in Fig. 371. It is made the same as the last, both as regards material and design, but has, in addition, hot and cold water draw-off taps, which of course might be fixed to any slop sink.

A description of slop sink recommended for use in a courtyard, and in connection with the dry earth system, is shown in Figs. 372—375.

Such sinks should not be constructed in a house, but may with advantage be fixed in a yard, at a distance from the dwelling, to admit of atmospheric disconnection.

The flap, although shown in the plate as made of timber, would be better if of wrought iron. When timber flaps are fixed, only hard wood, such as oak or elm, should be used, and the whole surface well tarred.

It will be seen that a small tap is provided immediately alongside the sink, so as to allow of pails, etc., being rinsed.

To reduce the chance of the rinsings being thrown on the surrounding ground, instead of again raising the flap, a surface channel is formed, leading into the sink. The slop-sink is protected by a small gun-metal grating.

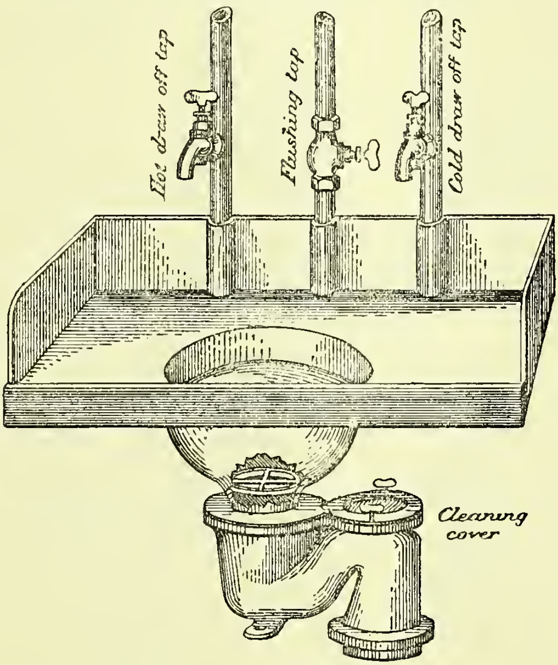


Fig. 371.—Slop Sink.

Scullery Sinks.—The position of these sinks should be against an external wall, so as to easily provide light by means of a window, and reduce the length of waste pipe.

Scullery sinks are best made of glazed stoneware, as shown in Plate XXVIII., page 354; but where liable to injury from rough usage, they should be of iron (*vide* Fig. 376).

Stone should never be used, as the description employed for this purpose, known as "freestone," is very absorbent, and in time becomes foul.

A trap of the class shown in Fig. 274 or 275, page 290, should be fixed immediately below the sink, and trap ventilation provided, so as to prevent any possibility of sewer-gas entering the house.

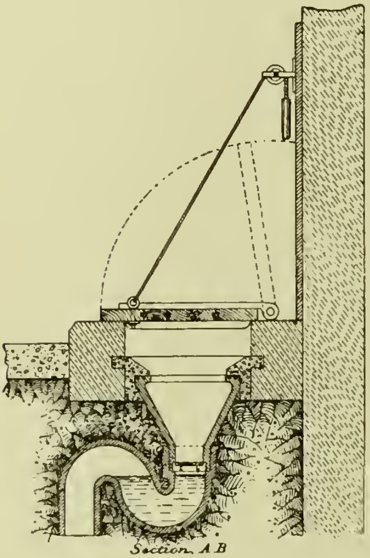


FIG. 372.—Section of Slop Sink.

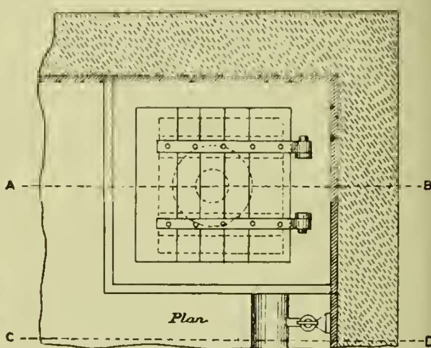


FIG. 373.

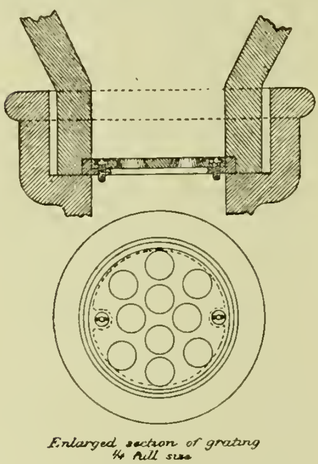


FIG. 374.

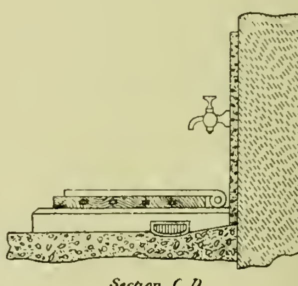
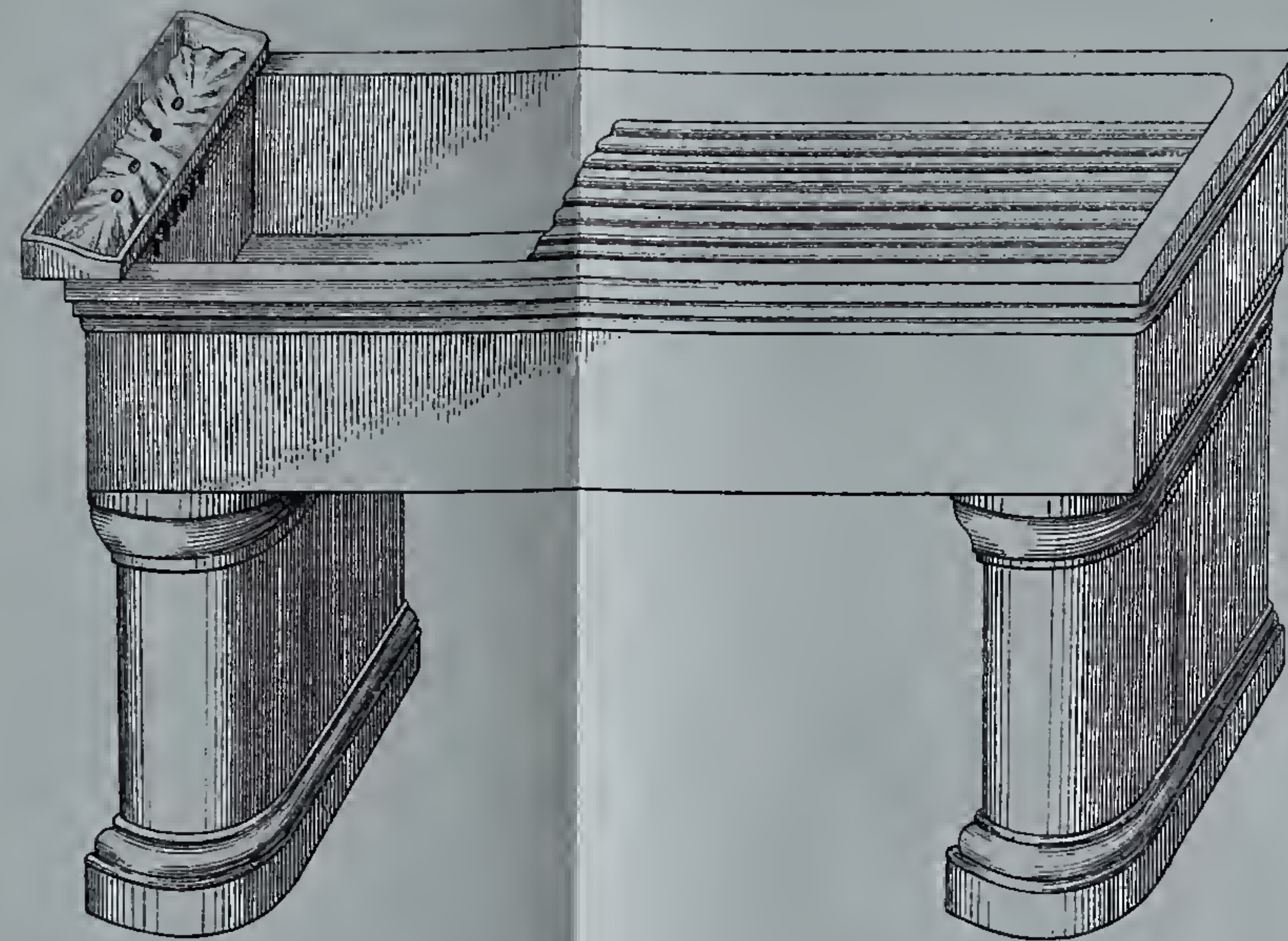


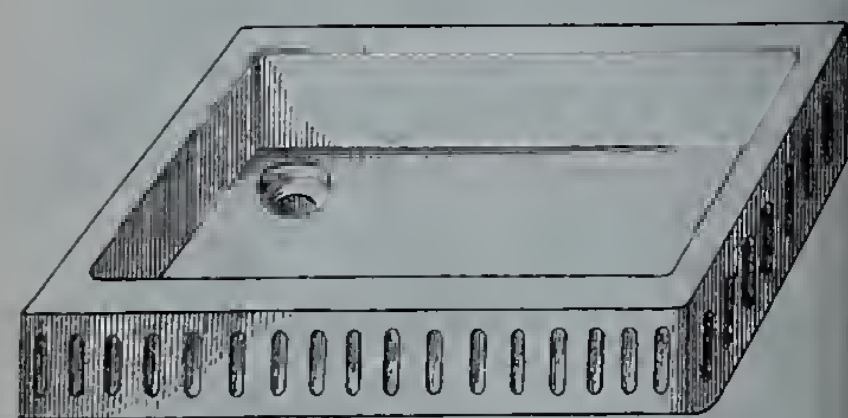
FIG. 375.

The waste pipe for ordinary sinks should be formed, as previously recommended, of ($1\frac{1}{2}$ inches to 2 inches) lead delivering over a trap with effective water seal.

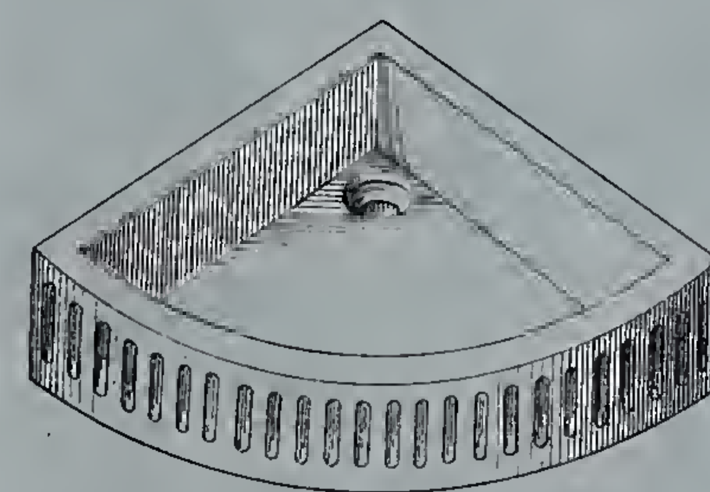
SINKS

PLATE XXVIII.





Fluted front.



Fluted front.

J. Akerman Photo-lith London

All such sinks should have good deep skirtings fixed around their upper edges, to protect the face of the wall from splashing, and consequent absorption of foul matter.

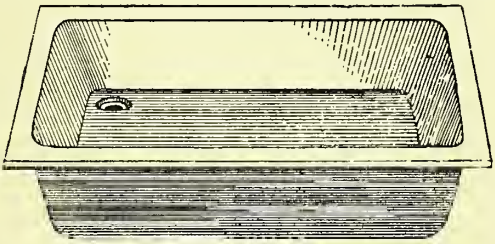


Fig. 376.—Scullery Sink.

Ducketts' Sink Fittings.—These are made in two varieties. No. 1 is shown in Fig. 377. The waste pipes are two inches in internal diameter, and made of highly glazed enamelled ware, with air-tight "Stanford" joint to trap; a brass grate is firmly lewised in the sink. The pipe A is made in two parts; the upper is of brass and soldered to the grating, and is made to telescope into the lower portion, which is of lead. A ware grate with a lead waste can be supplied if preferred. The outlet of the trap may be turned in any desired direction to suit position, or to remove the socket of waste pipe from the wall. When cleaning remove pipe A and the trap; the cleaner can then be passed through the waste pipe.

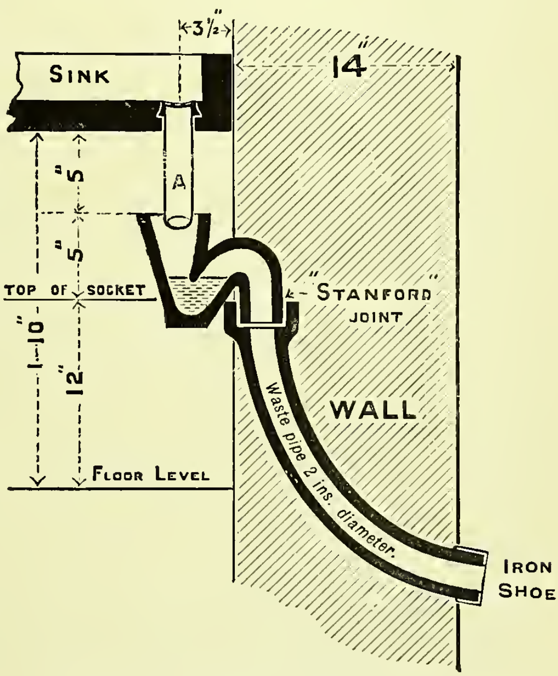


Fig. 377.—Ducketts' Patent Sink Fitting.

Pantry Sinks are intended for washing more delicate articles than scullery sinks.

They should be fixed in the butler's pantry or room, and are generally made of wood, lead lined, as that material is not so liable to damage glass, china, and silver, as stone, stoneware, or iron. Such sinks should not be less than fifteen or sixteen inches deep, in order to admit of a decanter being placed under the draw-off tap (Figs. 378—381).

The junction between the sides and bottom of lead-lined sinks should have the angle filled in with a wooden fillet, triangular in section, before the lead lining is fixed, to prevent the accumulation of dirt and facilitate cleaning. A good fall should be given towards the outlet,

LEAD-LINED PANTRY SINK.

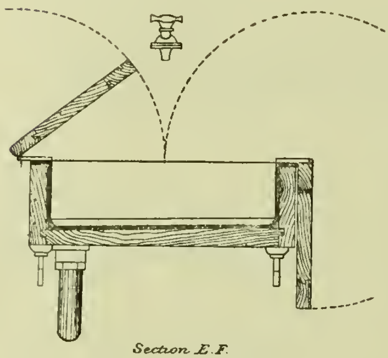


FIG. 378.

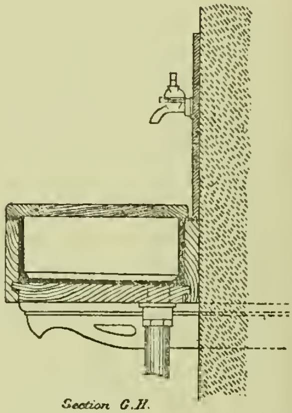


FIG. 379.

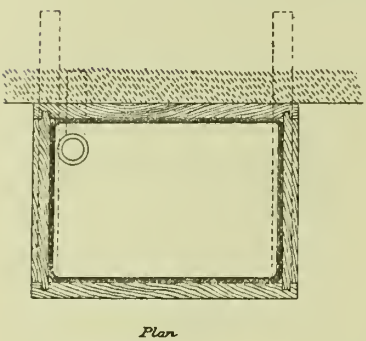


FIG. 380.

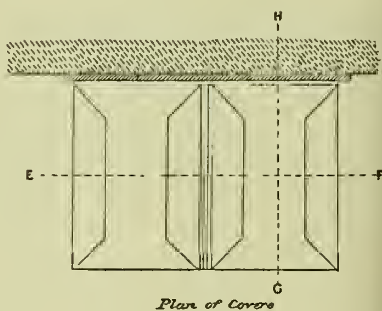


FIG. 381.

which should be placed in one of the back angles or corners nearest the wall.

The lead for lining these sinks should weigh 7 or 8 lbs. for the sides, and 10 or 12 lbs. per foot superficial for the bottom.

The opening in the bottom of the sink should be fitted with a counter-sunk washer, with back-nut and plug.

The waste of pantry sinks should conform in all other conditions to those recommended for scullery sinks, and a trap, selected from those illustrated in Fig. 274 or 275, page 306, should be used.

It will be found that a piece of indiarubber tube, a few inches long, fixed to the draw-off tap of a pantry sink, will save much chipping and breakage of glass and china.

Baths.—Fixed baths with hot and cold water laid on tend so much to economize domestic labour, and are so very convenient, that they are looked upon as a necessity in all modern houses, special bath-rooms being made for their reception.

Baths are made of a great variety of materials, viz., copper, zinc, iron, slate, glazed fire-clay, or porcelain, etc.

Copper baths are the most expensive, but, at the same time, are the most durable. They are generally enamelled, and when this wears off the enamelling can be renewed. They should be supported on a wooden framework, to prevent alteration of shape.

Zinc baths are made of thin sheet zinc, and require to be supported in the same way as copper baths, but are not so durable. They may be either painted or enamelled.

Iron baths are made either of cast or of sheet iron. They are generally painted, or enamelled in imitation of marble, but this covering material is very liable to damage and come off. With cast iron this is especially likely, partly owing to the metal being less elastic than other metals, and partly owing to the fact that iron is so readily oxidized when in contact with moisture. Iron baths are comparatively inexpensive, but they change colour after a time, and do not look as clean and nice as is usually desired. Cast-iron baths with curled edges have the advantage, in consequence of their strength, of being able to dispense with any wooden framing for their protection.

Slate baths are sometimes enamelled, but the enamel is liable to be chipped off. The disadvantage of the use of these baths when not enamelled is that, being of a dark colour, it is difficult to see if they are clean.

Slate baths being formed of slabs, the joints of which are made with red lead, are liable to leak, and the corners harbour dirt.

Porcelain baths are very durable, and the glaze with which they are covered is not easily damaged ; they are made in one piece, and have rounded angles and corners, in which dirt cannot collect. The colour is generally white, which also gives them a clean appearance. They are very cumbersome and heavy, and have the property of absorbing heat and not readily parting with it ; consequently, when warm water is used, its temperature is soon lowered. Heat being retained in this way would be an advantage if the bath was used by several people consecutively. To prevent risk of fracture from boiling water suddenly impinging on a part of it, especially in cold weather, care should be taken in filling the bath to admit some cold water first, and then gradually add hot water till the required temperature is reached.

For occasional use a copper, zinc, or block tin bath is preferable.

The floor on which baths rest should be composed of some non-absorbent material, such as tiles, concrete, etc., and if of wood, it should be protected with sheet lead, turned up a few inches all round so as to form a safe.

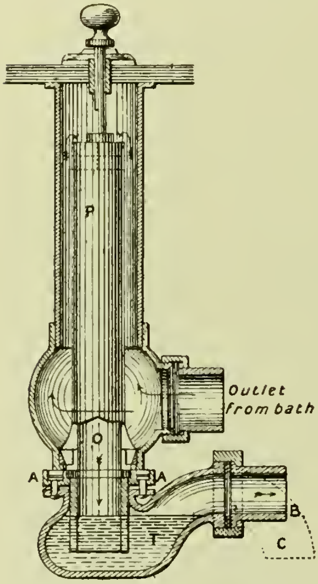


Fig. 382.—Valve for emptying Baths.

Wastes from Baths.—Whatever kind of bath is adopted, it is important to have means of rapidly emptying it.

All bath wastes should discharge with an open end outside the walls of the house into an open channel leading to a self-cleansing drain trap, such as are represented in Figs. 251—255, pages 299, 300. The main waste pipe should be carried up full size above the ridge of the house for ventilation, so as to be clear of all windows, etc. (Plate XV., page 280).

Long surface channels from baths and sinks leading to a gully are objectionable, as they are apt to catch a quantity of sand, which tends to choke the trap.

As a bath contains from 30 to 50 gallons of water, it should be made a means of flushing out the house drains. The size of the waste should not be less than from $1\frac{1}{2}$ to 2 inches in diameter, so as to discharge the contents at the rate of about 30 gallons per minute.

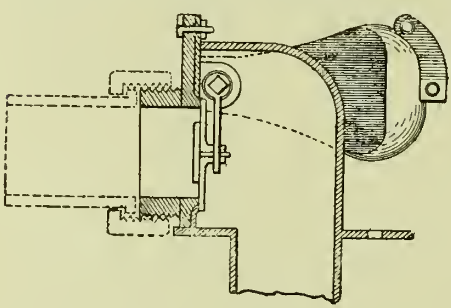


Fig. 383.—Flap-valve for Baths.

A form of valve made by Mr. G. Jennings is shown in Fig. 382, in which an overflow and trap are provided.

Fig. 383 is a form of flap-valve, made by Hellyer, for emptying baths rapidly; it, however, requires a separate trap and arrangement for overflow.

In some cases the orifice for the waste is also utilized for the admission of fresh water to the bath; this is, however, an objectionable system.

The discharge of so large a body of water through such small pipes is liable to unseal the trap at the bath, consequently trap ventilation as shown in Fig. 384, is very necessary.

Lavatory Basins.—The best position for a lavatory basin or range is against an external wall, in order to afford easy means of providing light

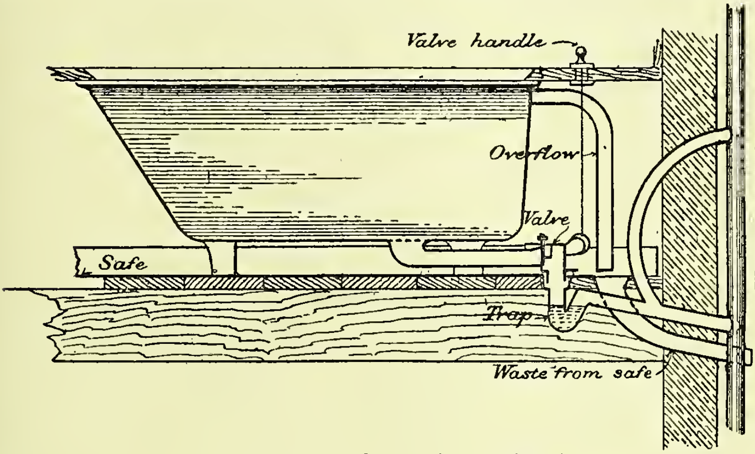


FIG. 384.—Ventilation of Trap of Bath.

and convenience of drainage. Lavatory basins should not be fitted up in a bedroom. They are a great convenience on the ground floor, and when hot and cold water are laid on, they save a great deal of domestic labour.

Lavatory basins are made of a variety of materials, such as iron—either enamelled, galvanized, or tinned—porcelain, and stoneware. Porcelain and stoneware basins have a cleaner appearance and wear better than iron. The basins are generally made in one piece, and fixed in a slab of marble or slate. In many instances the basin and slab are combined in one piece, and have recesses for soap, brushes, etc.

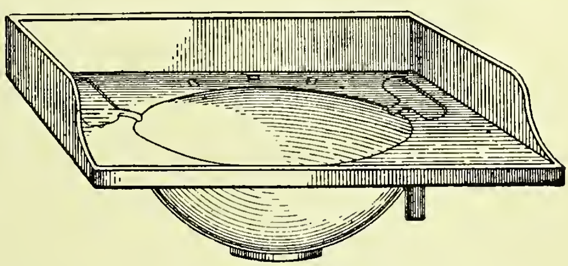


FIG. 385.—Lavatory Basin.

Fig. 385 is an example of a lavatory basin, with skirting, soap and brush tray.

The water supply in this case would be by bib or push taps.

The basin in Fig. 386 is provided with a flushing rim, the object of which is to assist in cleansing the sides of the basin.

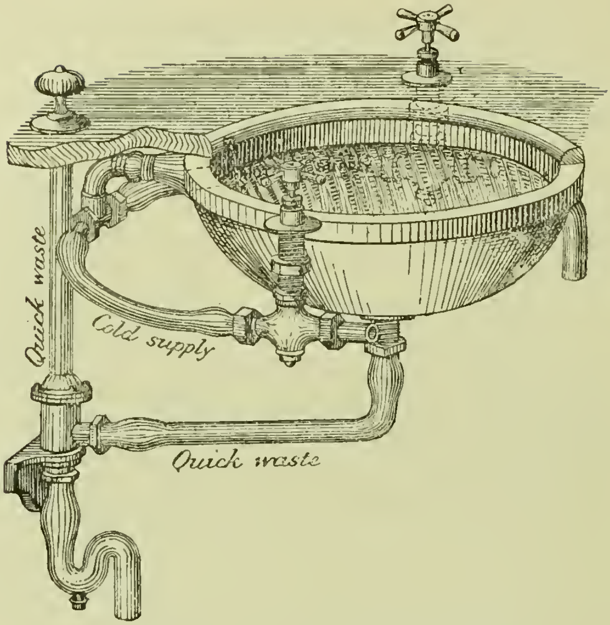


FIG. 386.—Lavatory Basin with Flushing Rim.

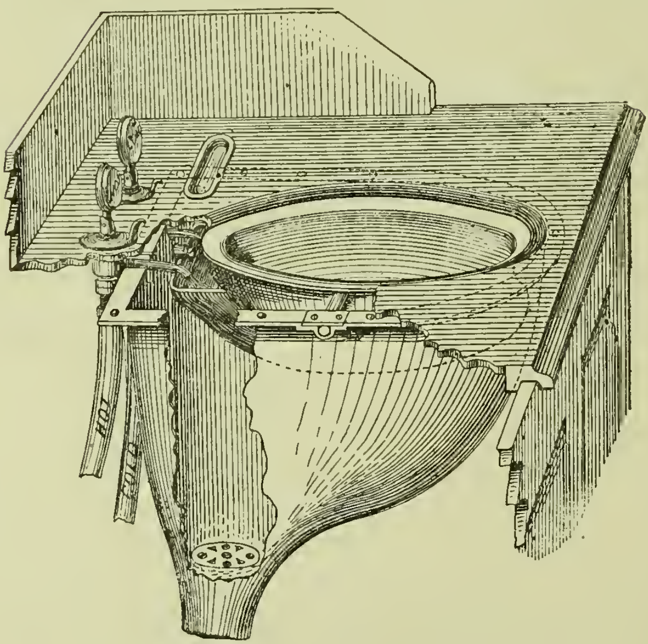


FIG. 387.—Tip-up Lavatory Basin.

The **Tip-up basin** (Fig. 387) has since been introduced; this basin is hung on pivots at the sides inside a funnel-shaped receptacle, into which the water is discharged by tipping. This description of apparatus is a doubtful improvement, for the surface of the receiver becomes coated with soap, etc., and being out of sight it is frequently omitted to be cleansed, and therefore becomes offensive.

The unsightly stain often noticed on stoneware basins, caused by constant dripping of water, may be removed very readily by the application of a little powdered chalk and a few drops of dilute ammonia by means of an old tooth-brush.

The waste from a lavatory basin should be large enough to admit of rapid discharge, and it is usually from 1 inch to $1\frac{1}{4}$ inches in diameter.

It should be trapped in the same way as recommended for wastes from baths, immediately below the basin.

The discharge should be into the open air, and into a proper self-cleansing trap outside the house.

If fixed on an upper floor, the top of the vertical waste pipe should be carried up beyond the eaves, clear of all windows, etc., for ventilation.

In ranges, *each* basin should be trapped before passing into the common waste. Provision should also be made to prevent syphonage, as in the case of a single basin, or bath (Fig. 384).

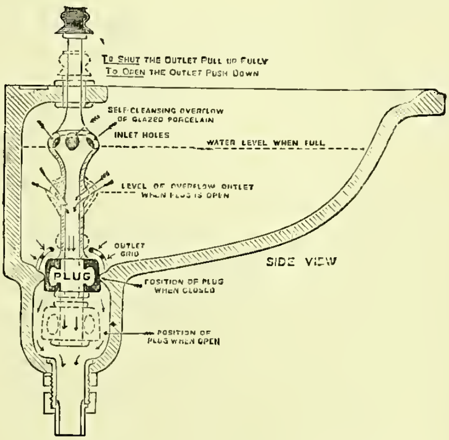


FIG. 388.—"Loco" Lavatory Basin.

Wastes from baths and lavatories may be combined.

The Patent "Loco" Lavatory Basin is shown in Fig. 388. It is claimed for this basin that there are no hidden pipes, no metal in contact with soapy water, no corrosion, and no foul accumulation. There is only one wearing part, viz., the plug, which is guaranteed to last five years, and can be renewed for sixpence. The apparatus can be taken to pieces by anybody, and put together again under one minute. A very rapid discharge, ensuring a perfectly clean condition of all surfaces, is effected. It forms an efficient drain flusher.

Lead Safes, or Trays.—To obviate the unsanitary condition produced in wooden floors, ceilings, etc., by splashing of slops and leakage of water, lead safes are used.

They are generally placed under baths, cisterns, w.c.'s, etc., on an upstair floor, and should be made of 5 or 6 lbs. lead, turned up at the edges for a few inches, viz., 6 inches for baths and cisterns, and 4 inches

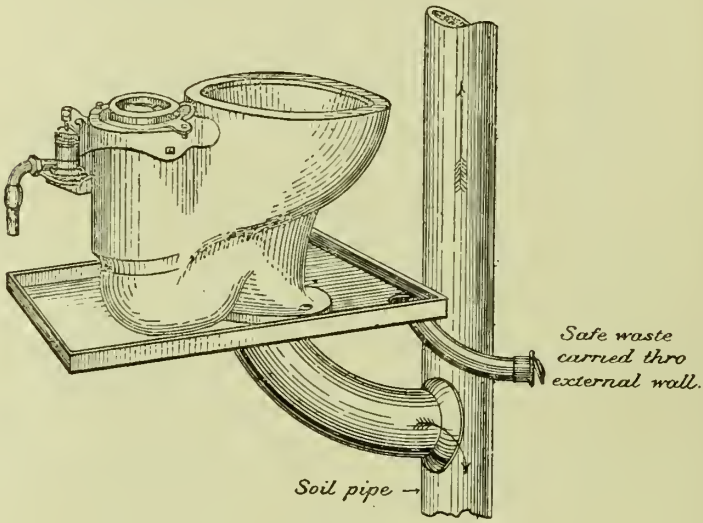


FIG. 389.

for closets, etc. The angles should be formed either by piglugs or by soldering (Fig. 389).

Hinged Flaps.—To prevent overflow from the safe, a lead pipe should be carried from it through the wall, the end being left open to the atmosphere, so as to discharge into the open air. Hinged flaps, *vide* Figs. 390, 391, are sometimes soldered at the end of the pipe to exclude draught.

HINGED FLAPS.

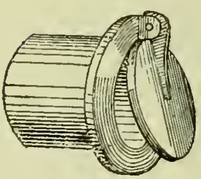


FIG. 390.

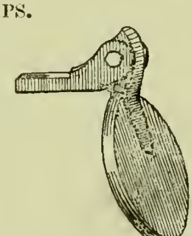


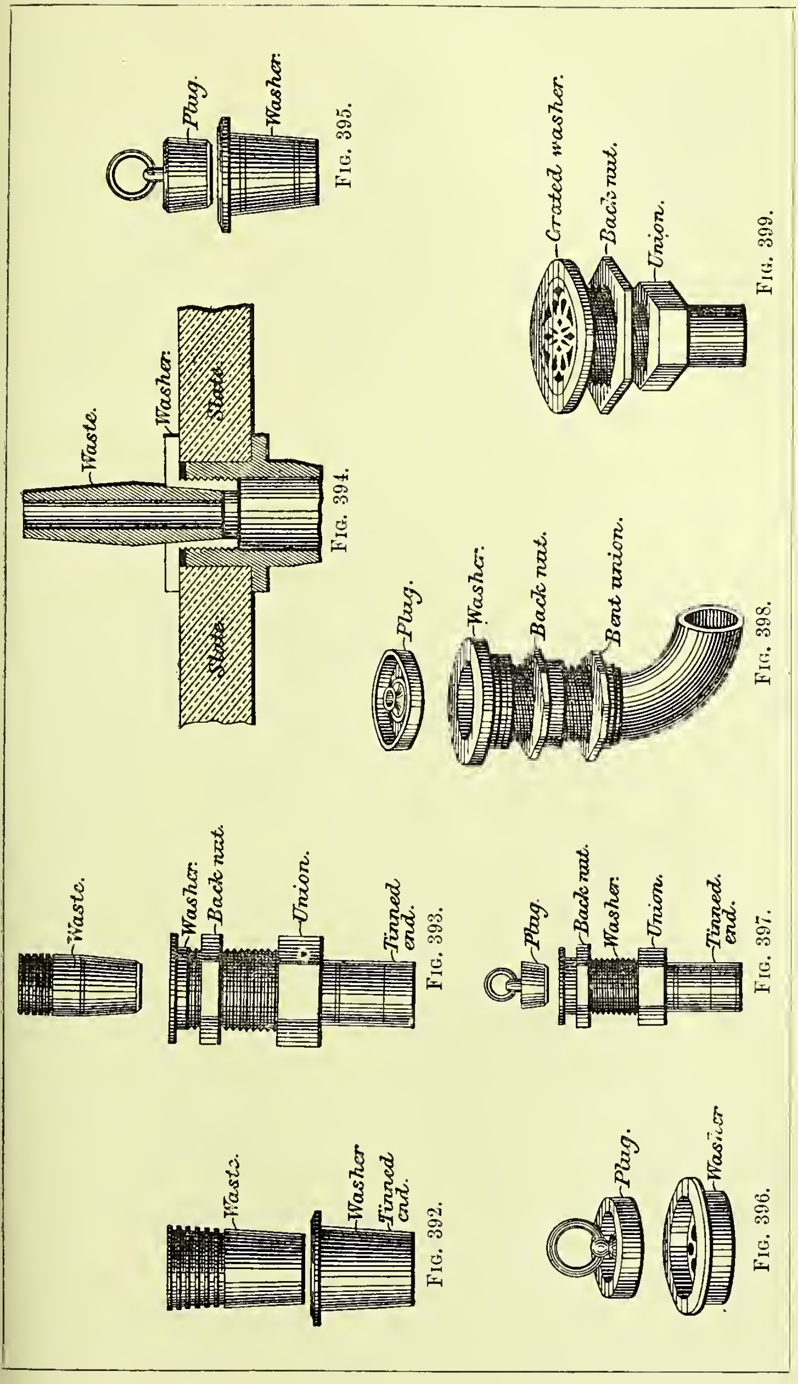
FIG. 391.

Washers, Plugs, and Wastes.—A variety of washers, plugs, and wastes, suitable for cisterns, sinks, and baths, is shown in Figs. 392—405.

Fig. 392 is a waste and washer that may be used for a lead-lined cistern.

Fig. 393 is suitable for an iron or slate cistern. The union is for attaching to a lead overflow pipe.

Fig. 394 is one that may also be used for slate cisterns.



FIGS. 392—399.—WASHERS, PLUGS, AND WASTES.

FIG. 400.

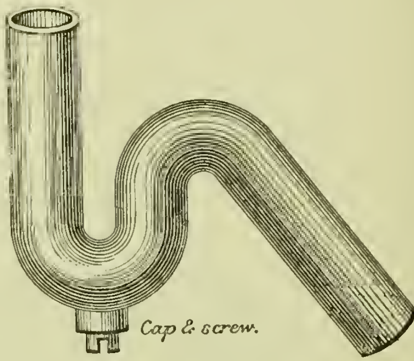


FIG. 402.

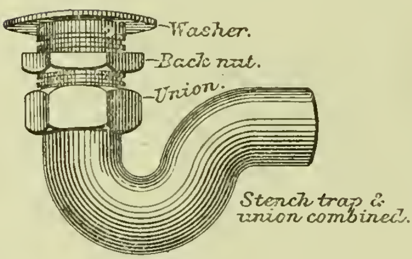


FIG. 401.

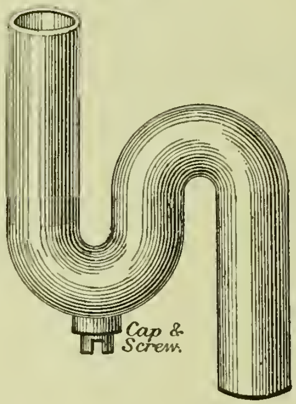


FIG. 403.

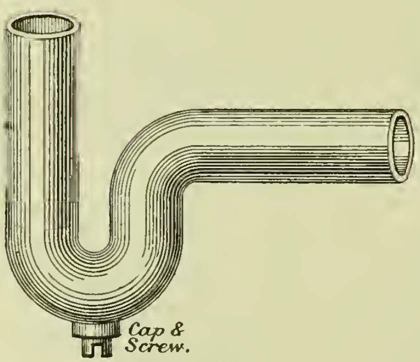


FIG. 404.

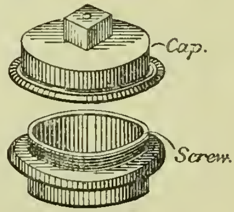


FIG. 405.

FIGS. 400—405.—SYPHONS, ETC., FOR SINKS.

The three above-mentioned should be used in connection with standing wastes.

Fig. 395 illustrates a plug and washer for a lead-lined sink.

Fig. 396 is a plug and washer, with perforated bottom, that might be used for a pantry sink.

Fig. 397 is a plug and washer suitable for a stoneware, iron, or slate sink, and a union for connection with a lead waste pipe.

Fig. 398 is a plug and washer that could be used for a bath, the bent union shown being supplied for connection to the lead pipe.

Fig. 399 is a grated washer and union for iron, slate, or stoneware sinks.

Fig. 400 is a grated washer and union for fixing as an overflow from a bath.

Fig. 401 is a plug, waste, and stench trap, and union combined, for a bath.

Figs. 402—404 are lead drawn traps, with cleansing eyes, that may be used under sinks or in similar situations.

Fig. 405 is a cap and screw that is used for fixing to the traps shown in Figs. 402—404, as a cleansing eye.

Where plugs are used, vulcanite is very frequently substituted for brass or gun-metal.

Flushing Drains.—It is becoming every day more apparent that provision for adequate flushing of drains in addition to other precautions is necessary in order to sweep away all deposit, and prevent the growth at the water line which so often takes place. Flushing is effected by a sudden and powerful discharge of a large volume of water into the drain, which completely fills it from invert to soffit, carrying all before it, and renewing to a great extent the air in the drain. In order to effect this, chambers for storing the water in, called flushing tanks, should be provided at the head of all foul drains, and adapted so as to discharge a sufficient volume of water suitable to the size and gradient of the drain intended to be flushed; the discharge should, as a rule, be automatic. Table 74 (page 350) shows the capacity generally considered necessary to be provided when designing a flushing chamber.

Brick or stone drains may be injured by too much flushing.

Iron drain-pipes have a great advantage in this respect.

Water for Flushing.—Water from reservoirs, streams, or other special sources, must sometimes be made available; but on a small scale it is usually more economical to store bath and ablution-room water, and some surface water, for this purpose.

Fig. 406 shows a flushing tank for utilizing surface water. It consists of two chambers, in the first of which silt is collected; the water overflows from it into the second chamber, and from thence it is discharged when full by means of a syphon connected with the drain. The passage of sewer-gas is prevented by a trap at the junction of the syphon arm with the drain.

TABLE 77.

Size of Pipe. Diameter—Inches.	Gradient of Drain—1 in.	Capacity of Chamber. Gallons.
4	40	30
	50	40
6	60	60
	100	100
	200	160
9	100	200
	150	250
	200	300
	300	400

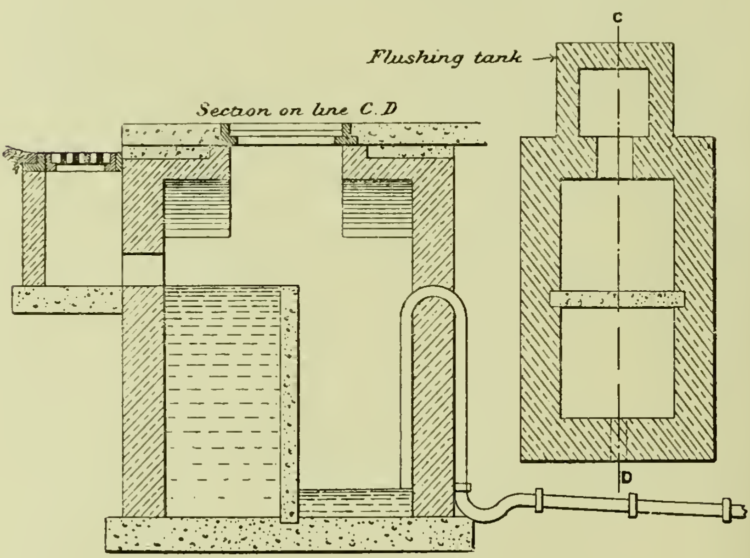


FIG. 406.—Flushing Tank for utilizing Surface Water.

Syphons.—The introduction of systematic sewer flushing dates back about twenty years. Mr. Rogers Field, the well-known sanitary expert, had, in conjunction with Mr. Bailey-Denton, made use of syphons to bring about the automatic discharge of sewage from settling tanks to a filtration area. The system of what is known as intermittent filtration was thus inaugurated. Prior to this time, where land had been used as a filtering medium, it was customary to allow the continuous flow of sewage upon it. The land became sewage-sick, and filtration was checked, the effluent passed off from such land being frequently as noxious as the sewage itself. The intervals of work and rest brought about by this intermittent discharge fitted the land to receive its sewage, and to deal with it so effectively that a less area so used would give a better result than with the larger area when the continuous flow was adopted.

The introduction of syphons for sewage disposal led to their use in sewers. The syphon known as Field's Patent was probably the first used for this purpose. A flushing chamber (Fig. 407), fitted with such a syphon, if placed at the dead end of a sewer, must necessarily exert a beneficial effect upon that sewer. No deposit can remain in a sewer so

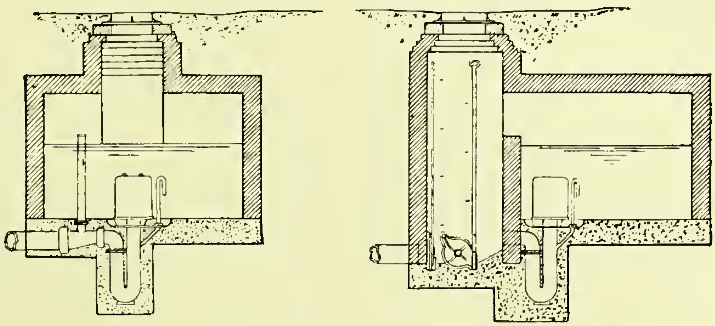


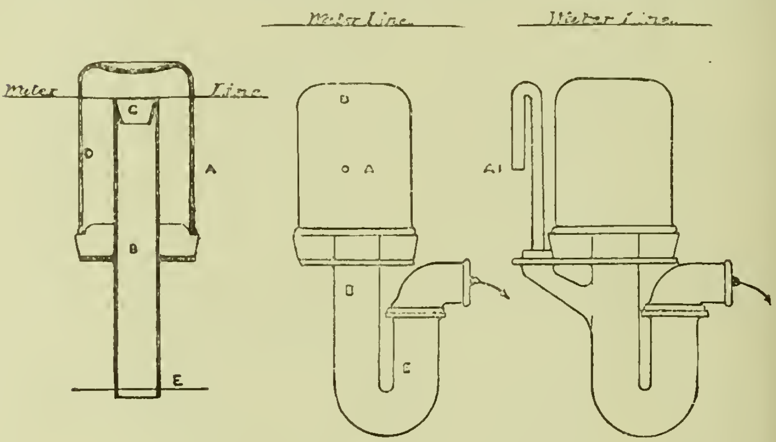
Fig. 407.—Adams' Automatic Flushing Syphon.

flushed, and a sewer having an insufficient grade may, by the use of flush tanks, be made equally satisfactory with that having a self-cleansing grade. By the regular (because automatic) flushing of sewers sewer-gas generation has been reduced to a remarkable extent, and it may be said, without fear of contradiction, that, given a proper distribution of automatic flushing chambers, the absolute prevention of sewer-gas is certain.

The objections to the free use of such tanks are, firstly, the cost of the water used, this ordinarily belonging to a private company ; secondly, that the water itself expended on sewer flushing is added to, and thus becomes, a part of the sewage to be treated at the outfall works.

For these reasons, it will be seen that it is desirable only to pass into a sewer the water actually required to flush it, and that any expended upon bringing the apparatus into work may be regarded as so much waste, or worse.

Automatic syphons may be divided into two classes—those from which air is extracted by water passed through, and those in which air is confined between the trap at foot and the rising liquid in tank. The first of this class, Mr. Field's (Fig 408), consists of an inner tube (B), having an annular lip or cone (C) placed at its summit. This tube is covered by a dome (D), or closed tube of larger diameter. The extremity of the syphon is lightly sealed in water at E. The apparatus now being placed in a tank or chamber, and supplied by liquid from any desired source, this liquid, upon rising to the lip level of the inner tube of syphon, will be thrown by the cone clear of the sides, and, falling through the space within, each drop will extract a given amount of air, a partial vacuum will be gradually formed, and syphonic action ensue; the time taken to effect this object being dependent upon the size of the syphon itself and the flow of liquid passed through



FIGS. 408, 409, and 410.—Flushing Syphons.

it. A small air or sniff hole (A) is pierced through the dome, to allow ingress of air, and thus break syphonic action. With a small syphon the loss of water is not excessive; with a large one it will be serious. The use of syphons of this type is therefore restricted ordinarily to the smaller sizes. Mr. Adams' (of Adams & Co.) is the first of the second class. It is very similar in construction to that last-named, but with the important difference that, in lieu of the light water seal at foot, this syphon has what is known as a "deep trap." No cone or lip is employed, the intention being not to extract air, but to enclose it. Thus the rising liquid around the syphon gradually increases the pressure of the air within, its resistance being equal to that of the column of water in the deep trap when a state of equilibrium is attained. If, however, this latter point is reached, and the volume of air within is in excess of the water displaced, a "blow" follows, the pressure within is momentarily reduced, and the rush of water from above, through the apparatus, brings about syphonic action. The gauge of volume may be the dimensions of the syphon itself, or an air-hole in dome may be employed. The air-hole, if large, however, retards the rate of discharge, and if small, is apt to become choked. Mr. Adams prefers to adopt a side pipe, which, being connected to the lower limb, has not an appreciable effect upon the discharge. This pipe serves to regulate the amount of air within, and also to break syphonic action. Relying as it does, not upon water passed through, but upon a given height in flush chamber being reached, this syphon has found wide acceptance (figures show, of all makers combined, 65 to 70 per cent. are supplied by Mr. Adams' firm). Other syphons are used, but all are more or less variations of the two types here described.

Fig. 409 shows the principle of Adams' syphon, where B is the inner tube, D the dome, A the air-hole, and E the deep trap at outgo.

Fig. 410 also shows this syphon, but in lieu of the air-hole the side pipe A is employed.

There is little actual data bearing upon sewer flushing available. Each engineer has his own practice. It is evident, however, that the requirements of a sewer will depend upon its diameter, length, grade, and normal flow. Tests made by Mr. Adams support the natural supposition that, to calculate the capacity of a flushing chamber, the theoretical velocity at the minimum flow should be taken, and the contents of such a sewer for the distance desired to flush. Then, given the depth, and thus the volume of sewage required to give a self-cleansing flow, the difference between these two sums will be the capacity of chamber or gallons required. In acceleration of this flow there will be a constant, due to the initial velocity or rate of discharge from flushing chamber. The flow in sewer should be in no case less than at rate of two and a half feet per second. The length of a sewer flushed will depend upon the dimensions of the flushing chamber. It is found convenient ordinarily to make these for 9-inch sewers, 300 to 400 gallons capacity; for 12-inch, 400 to 500; 15-inch, 600 to 800, and so on. It is quite evident that in sewering (new districts particularly) gradients are taken which are sufficient assuming the sewer to be half full; but that, as most frequently such sewers are partially so only, the gradients are insufficient, and, unless flushing is systematically resorted to, it is impossible to avoid the generation of sewer-gases.

Rogers Field's 1889 Patent Automatic Flushing Syphon.—This apparatus is specially made for flushing sewers and drains. The illustration (Fig. 411*) shows a section of the syphon, the action of which is as follows:—

* Figs. 411—416, illustrating FIELD'S SYPHON, will be found on the folding sheet facing page 370.

The lower end dips into the water in the trapping-box (Fig. 412). As the water in the chamber, or cistern, rises, the air on the inside of the syphon is compressed and is gradually expelled through the trap at the end of the inner leg. The water rises on the inside of the dome of syphon until it reaches the level of the lip or adjutage. The first drops which trickle over fall vertically and expel a further quantity of air, and this action continues until a partial vacuum is formed in the inner leg, and syphonic action is set up, and the whole contents of the chamber is discharged with great velocity and force.

This illustration (Fig. 413) shows the syphon fitted into a brickwork chamber, with cast-iron trapping-box, for flushing sewers, etc.

The illustration (Fig. 414) shows section of chamber, with syphon fixed in position. Fig. 415 gives a plan of the flushing chamber.

The principal points about these syphons are that there are no moving parts or valves to choke up and get out of order. The discharge is certain with a drop-by-drop supply. The force and velocity of flush is very great. The syphons will work with clean water or with sewage.

For flushing house drains the syphons are made in galvanised wrought iron (Fig. 416) fitted into galvanised cisterns. The manufacturers of the above are Messrs. Bowes, Scott & Western, Ltd.

Miller Patent Automatic Flushing Syphon.—This apparatus is shown in Fig. 417, which represents a "Special" design, which is stated to be a great success, affording a very rapid full-bore discharge, about 40 per cent. faster than any other syphon. It is provided with a deep seal trap which cannot syphon out or evaporate. The Miller Flushing Syphon Syndicate supply another special design for shallow depths.

The syphon is very simple in construction, consisting of a bent tube and mouthpiece cast together, and an iron bell, which is intended to be placed over the longer arm of the syphon, being supported on brackets cast on the trap.

The action of the syphon is as follows:—As the water entering the tank rises above the lower edge of the bell, it encloses the air within, the lower portion of the **U** or trap being, of course, filled with water. As the water level in the tank rises, the confined air gradually forces the water out of the long leg of the trap, until a point is reached when the air just endeavours to escape round the lower bend. Now as the difference of water level in the two legs equals the difference of the levels between the water in the tank and the water within the bell, it will be seen that the column of water in the short discharge leg has practically the same depth as the head of water in the tank above the level at which it stands in the bell. The two columns of water therefore counterbalance each other at a certain fixed depth in the tank. As soon as this depth is increased by a further supply, however small,

AUTOMATIC FLUSHING SYPHON (ROGERS FIELD'S 1889 PATENT).

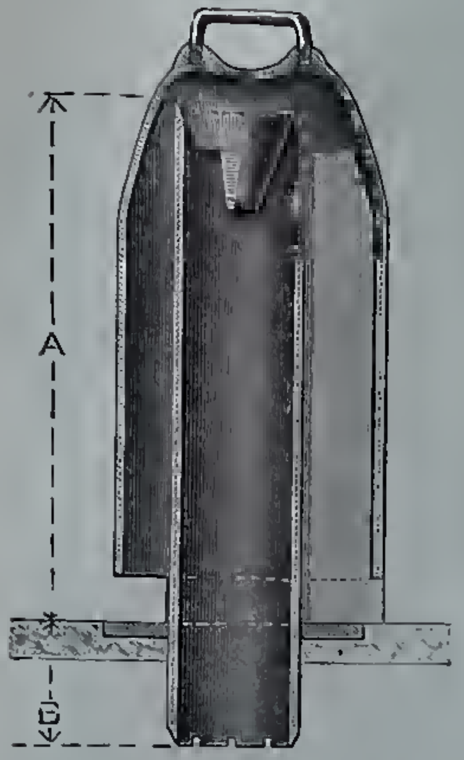


FIG. 411.—Section of Syphon.

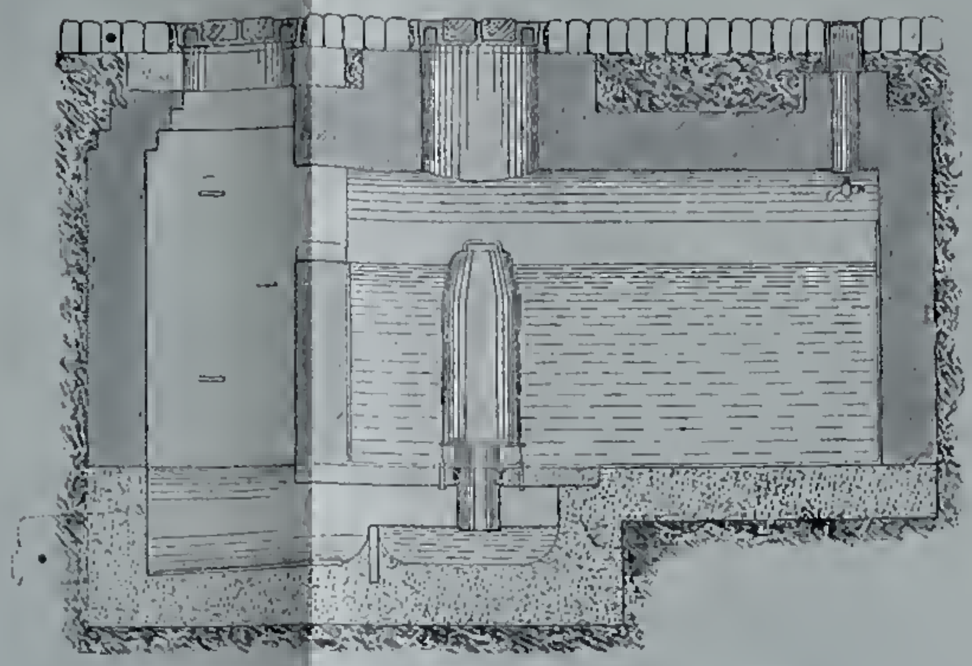


FIG. 412.—Longitudinal Section, showing Chamber.

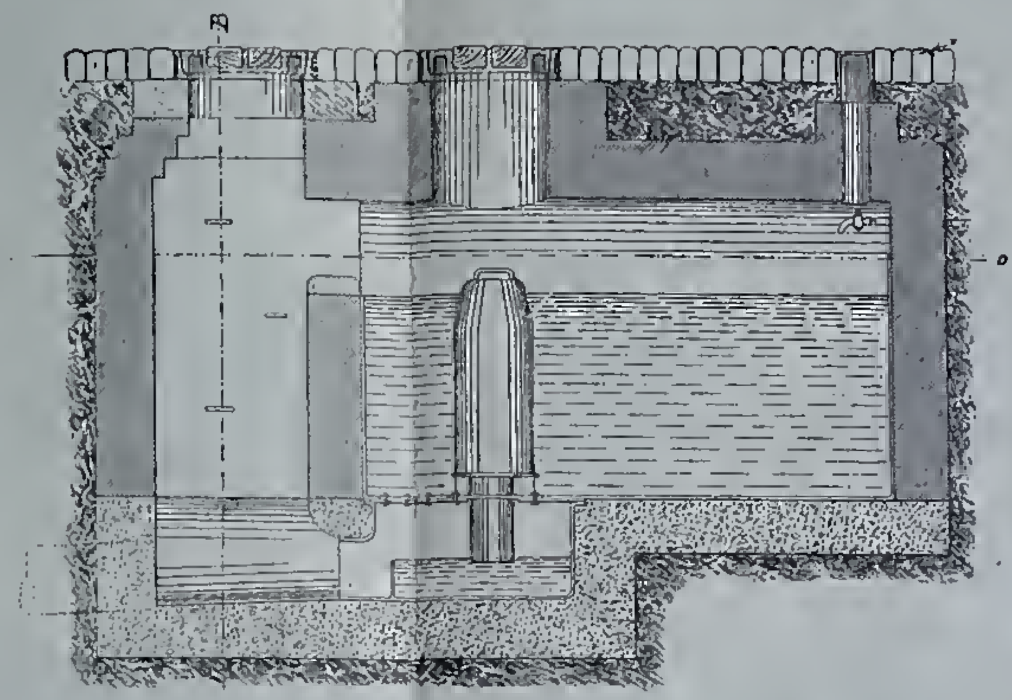


FIG. 413.—Longitudinal Section, showing Chamber with Iron Trapping Box.

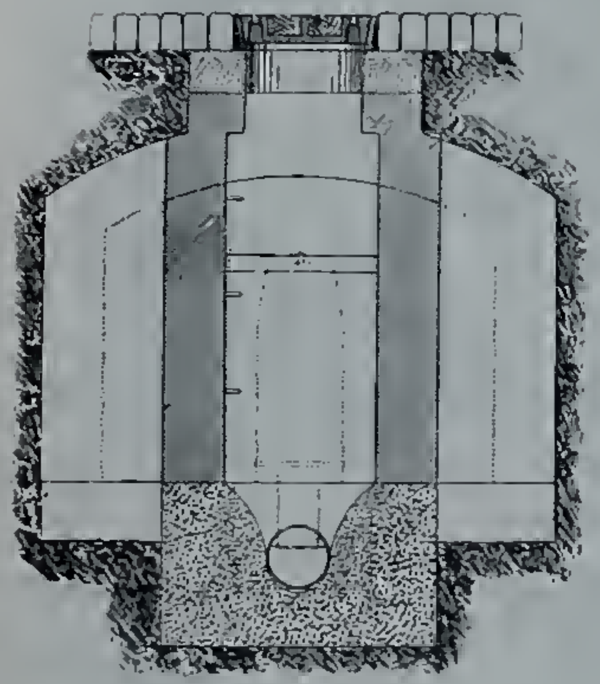


FIG. 414.—Cross Section of Chamber, with Syphon in position.

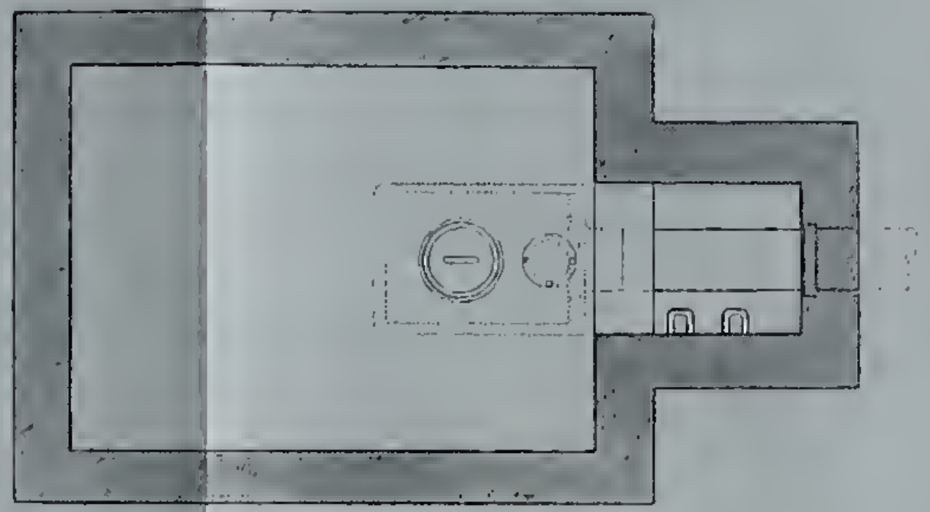


FIG. 415.—Plan of Flushing Chamber.

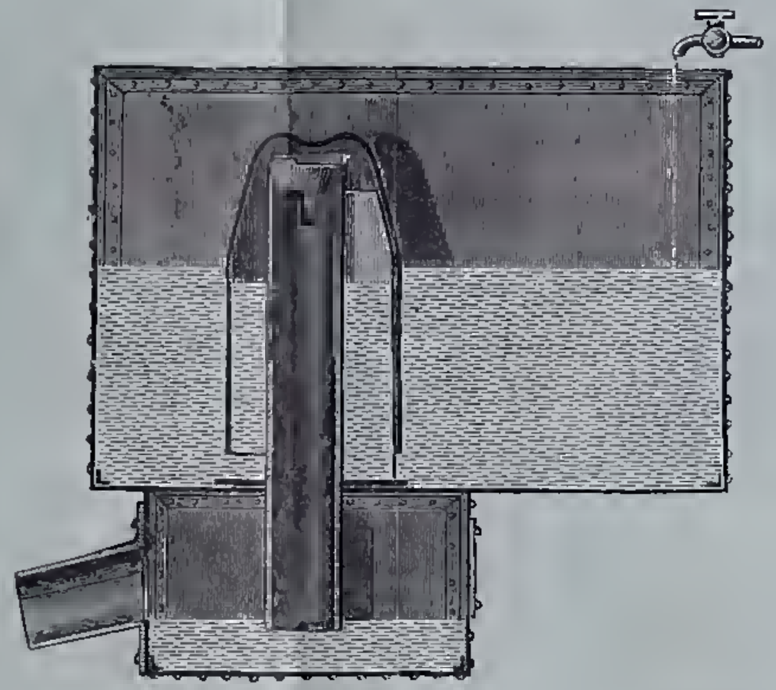


FIG. 416.—Showing Syphon fitted to Galvanized Iron Cistern.

To face page 370.




a portion of the confined air is forced around the lower bend, and by its upward rush carries with it some of the water in the short leg, thus destroying the equilibrium. But the secret of this invention is the free projection of the overflow edge, which allows of the instantaneous escape or falling away of the heaved-up water. Thus, if the discharge mouth were formed as an ordinary bend, the syphon would not act (although the confined air rushes around the lower bend), for the simple

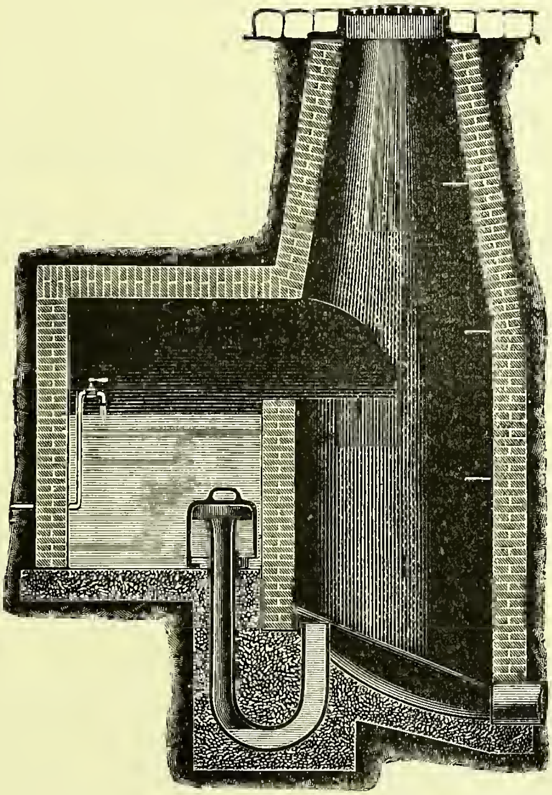


Fig. 417.—Miller Flushing Syphon, "Special" Design.

reason that the heaved-up water has no means of instantaneous escape, and therefore the equilibrium is not sufficiently disturbed. It will thus be seen that the action of the syphon depends, not on the escape of air, but on the sudden reduction of a counterbalancing column of water.

Repeated trials have shown that a six-inch syphon will discharge full bore a 500-gallon tank, fed so slowly as only to be filled in fourteen days. There being no internal obstruction, the discharge is extremely rapid. There is, it will be seen, a deep water well between the flushing tank and the sewer, which is of course an advantage. We have had the opportunity of seeing one of these syphons at work in the excellent Sanitary Museum at Hornsey, and, though severely tried, the syphon worked perfectly. As will be seen by a reference to Fig. 417, the syphon chamber can be very neatly combined with a manhole. No special mouthpiece is then required ; the mouth of the discharge pipe stands quite clear, and

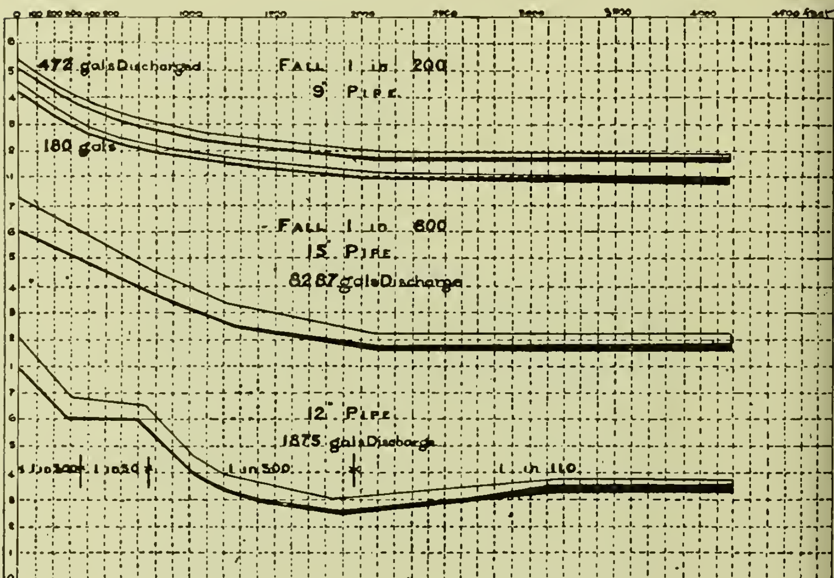


FIG. 418.—Sewer Flushing Diagram.

delivers the water into a concrete basin, from which it rushes down into the sewer.

The English representative of the makers is Mr. Albert Wollheim, A.M.I.C.E.

There are also many other makers of syphons, such as Messrs. W. H. Bodin & Co., and others.

Velocity Diagrams (Fig. 418).—These examples are taken from diagrams prepared by Mr. S. H. Adams,* showing, from experiments carried out by him, the actual depth, etc., of a given discharge in a sewer.

The horizontal lines give velocity in feet per second, and the vertical lines distances in feet.

Ducketts' Automatic Tippers for Flushing Sewers, etc. (Fig. 419), are made in various sizes, adapted from three to one hundred gallons flush.

* E. & F. N. Spon, Ltd.

They are very powerful, require no attention, and have no mechanism likely to get out of order. The water supply may either be from the town's main, or surface water from the roofs, streets, sinks, etc., may thus be utilized for flushing. The tippers are made of salt-glazed earthenware, and rest on gun-metal bearings.

Manholes are sometimes used in towns for flushing purposes, and special chambers can be made in connection with them, with flushing doors, similar to those shown in Plate VII., page 18, in which the sewage and storm water can be retained by a sluice valve, and when a sufficient accumulation has taken place, it is liberated by opening the sluice, either automatically or by hand. In the latter case, to provide against inattention, the sluice gate should not cover the whole orifice of the

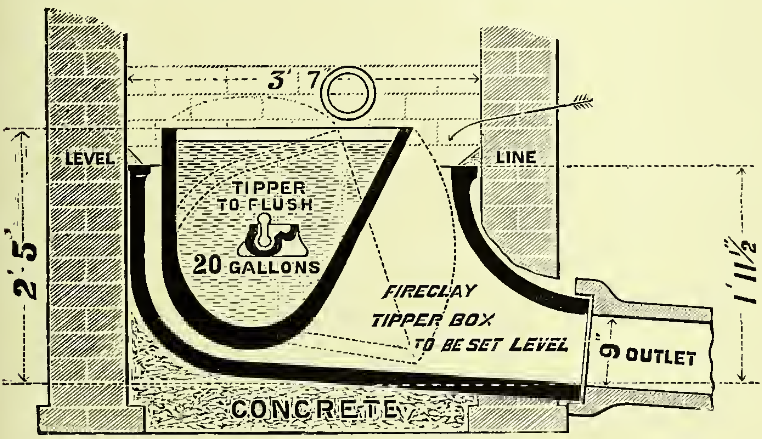


FIG. 419.—Ducketts' Automatic Tipper.

sewer. A good proportion for the gate is from one-half to two-thirds the area of the sewer. The method indicated tends to raise the water line temporarily above its ordinary limit, the discharge leaves a large surface of the interior of the sewer fouled, from which, owing to decomposition, gases are continually being given off.

It is, therefore, better to use clean water for flushing purposes, as it is necessary not only to remove the deposit, but also to cleanse the whole of the interior of the sewer from any matter adhering to it.

Movable Tanks.—In some towns, tanks with a capacity of 2,000 to 3,000 gallons, placed on wheels, previously filled from a hydrant, are brought into position near openings in the sewers. They are discharged through a 12-inch or 15-inch outlet for flushing the sewers.

Fire Engine.—Fire engines may also be used advantageously for drains up to nine inches diameter.

Order of Flushing Drains.—When a system of flushing is established, the lower parts of the sewers should first be flushed, and then the upper parts in succession. The flushing of a drain has a tendency to cause a backing-up in the branch drains running into it, especially when the fall is small, and for this reason it may be necessary to flush all the branches separately, and even to clear them with rods.

It has been recommended to make arrangements for householders to flush their drains periodically and at the same time, at special hours arranged for the locality, so as to carry practically into effect the system just advocated.

CHAPTER XI.

SURFACE WATER COLLECTION.

Surface Water.—Surface water includes all water collected from roofs of buildings, paved and other surfaces.

How Collected.—Roof water is collected by gutters and down pipes.

Eaves' Gutters.—Eaves' gutters should be attached at a slope of 1 in 60, unless of a sufficiently large section to retain the water, when, for the sake of appearance, they are fixed horizontally.

The sections vary much in shape ; the ordinary pattern is half-round (Figs. 420—427), but more ornamental forms are often used.

Down Pipes.—Down pipes (Figs. 428—437) are made of cast iron, with hopper heads to receive the water from the guttering ; also swan necks, off-sets, bends, and shoes.

The form of their section also varies from circular to square, and they are made more or less ornamental.

Joints.—The joints should be stanched with tow, and then filled with red or white lead.

Not to be Led into a Drain for Foul Water.—Rain-water pipes should never be led into a drain for sewage or foul water, but should discharge over outside gullies.

Along Surface Channel.—It is also sometimes economical to lead the water from a down pipe along a surface channel to the nearest surface-water gully, instead of providing a special gully immediately under it.

From Roads.—Surface-water from roads, parades, and pavements is collected by giving a fall or current to the surface, and by forming surface channels in paving, concrete, asphalte, etc. ; tar paving is also much used for this purpose in many towns.

Surface Gutters, Fall of.—Surface gutters should have a fall of $1\frac{1}{2}$ inches in 10 feet, or 1 in 80, though the fall is sometimes as little as 1 in 125.

Surface of Road.—The surface of a road should have a fall towards the side channels of from 1 in 20 to 1 in 40.

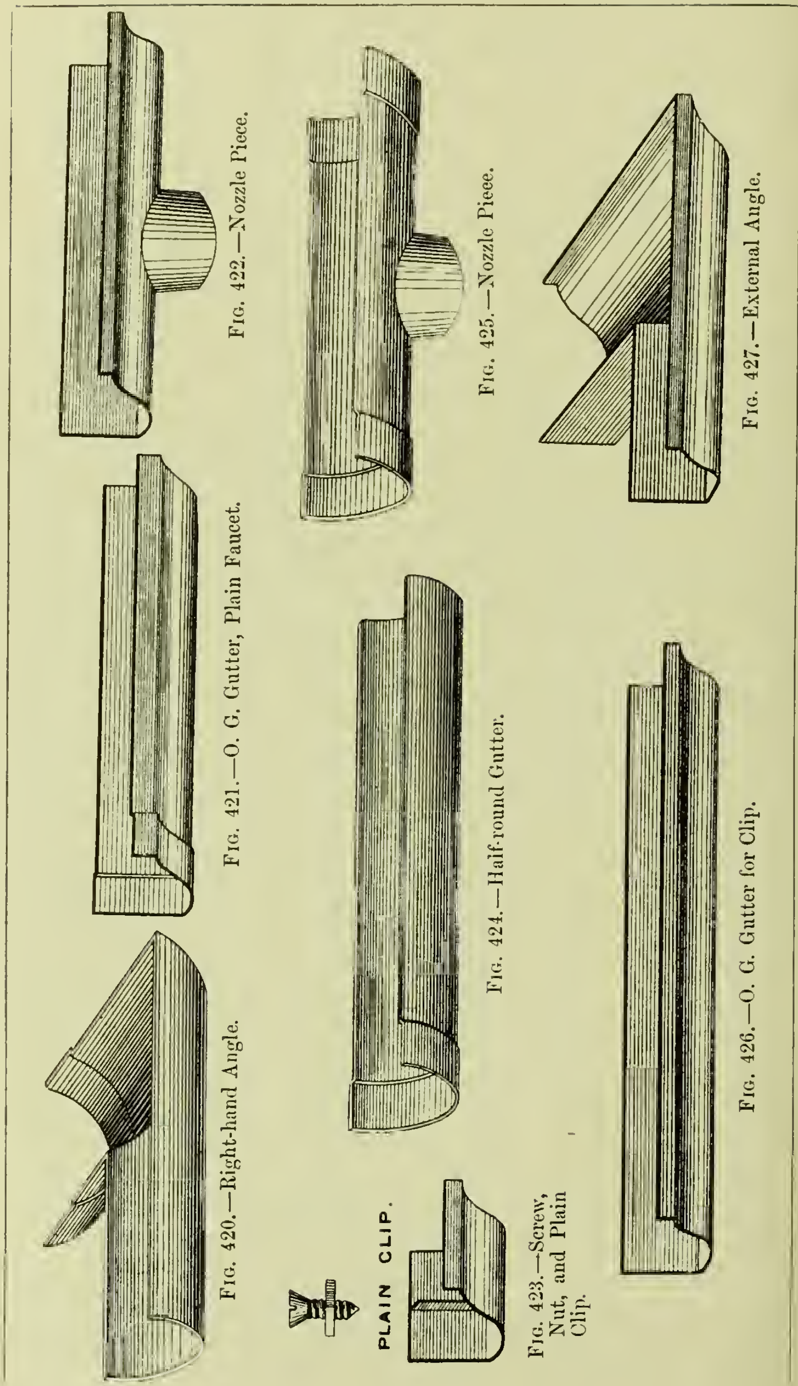


Fig. 420.—Right-hand Angle.

Fig. 421.—O. G. Gutter, Plain Faucet.

Fig. 422.—Nozzle Piece.

Fig. 423.—Screw, Nut, and Plain Clip.

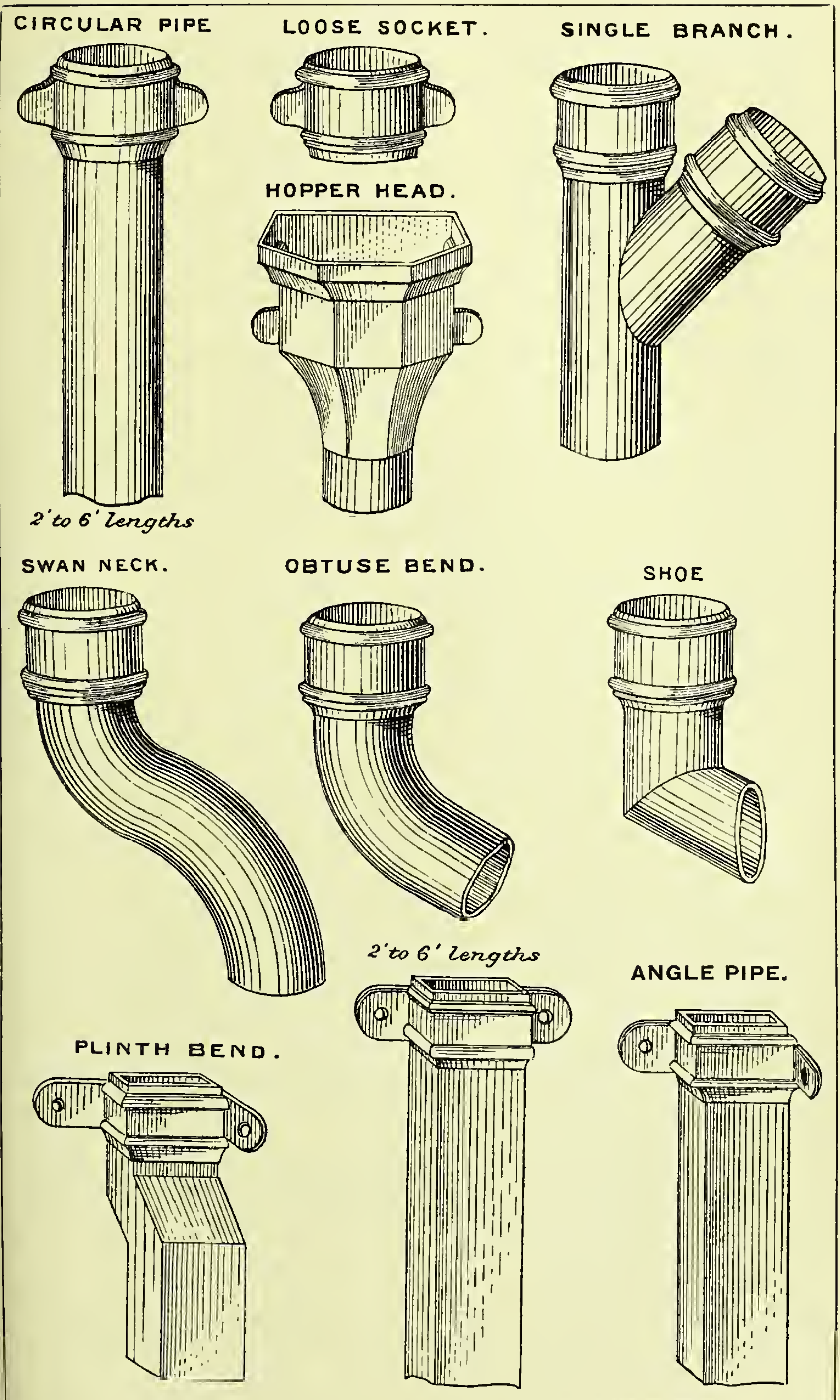
Fig. 424.—Half-round Gutter.

Fig. 425.—Nozzle Piece.

Fig. 426.—O. G. Gutter for Clip.

Fig. 427.—External Angle.

Figs. 420—427.—Eaves' Gutters.



FIGS. 428—437.—RAIN-WATER PIPES.

Drains.—As the water thus collected would at times accumulate into a considerable stream, besides being liable to get dammed up and overflow the channels, if kept on the surface, it passes at intervals of about 100 feet to 200 feet, or even more where the ground is very steep, through gratings into underground drains, which carry it off to some outlet.

Catch-pits.—As a good deal of sand and dirt is washed off roads and open spaces by the surface-water, a catch-pit should be formed underneath the grating, in which the silt may be deposited, and from which it can be readily removed on raising the grating or other cover, which should be hinged for this purpose.

The following are the requirements which should be kept in view in selecting the kind of catch-pit, or gully, to be used to suit any system of drainage:—

(1.) They should have sufficient area to carry off all the water led to them.

(2.) They should not be easily choked on the surface by leaves or other *débris.*

(3.) The pit should be sufficiently large to retain all sand or road detritus, and prevent it being washed into the drain-pipe.

(4.) The grating should be amply strong to resist any traffic that may come upon it.

(5.) They should give the least possible obstruction to traffic.

(6.) They should be made in such a manner as to be readily cleaned out.

(7.) The drain from it should be easily freed from any obstruction.

(8.) If used in connection with a sewer, they should be trapped, the water seal being 4 inches deep, to prevent escape of sewer-gas.

The catch-pit may be built of brickwork in cement 4½ or 9 inches thick, or formed in stoneware, and vary in size according to the requirements of the situation.

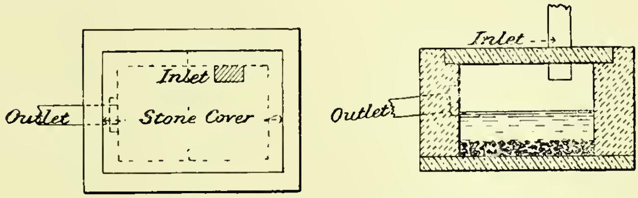
If made of brickwork, it should be rendered in cement on the inner faces; a stoneware junction pipe set on end will often answer the purpose.

The bottom should be formed of concrete or a 2-inch York flag, extending underneath the sides. From this catch-pit the water is carried off by stoneware drain-pipes, the outlet being from six inches to three feet above the bottom.

(a.) **Separate System.**—Under this system, traps for surface water are not required, and it is only necessary to collect the silt, leaves, etc., in a catch-pit, so as to prevent them from entering and choking the drain.

The catch-pit in Fig. 488 is intended to arrest the passage into the drain of leaves and dirt from the roof of a building.

The slab of stone protects the drain from being improperly used by slops being poured into it, which might be the case if the stone was replaced by an iron grating.



Plan. Section.

FIG. 438.—Catch-pit for Surface Water.

The cover should be capable of being readily removed for the purpose of clearing out the accumulation in the catch-pit.

The catch-pit shown in Figs. 439—441 is intended for use on a line of drain to intercept road detritus, etc., during a freshet. Sewage should never be allowed to flow through such catch-pits.

Mason's, or dip traps, are sometimes used for surface drainage in connection with this system, but are of no value, as the tongue is not required.

(b.) **Combined System.**—The following traps are used as silt collectors on this system.

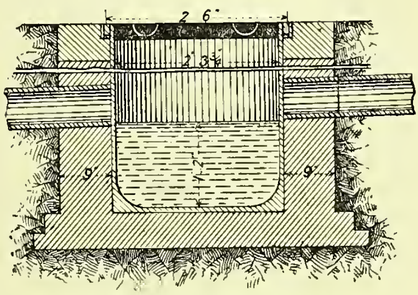


FIG. 439.

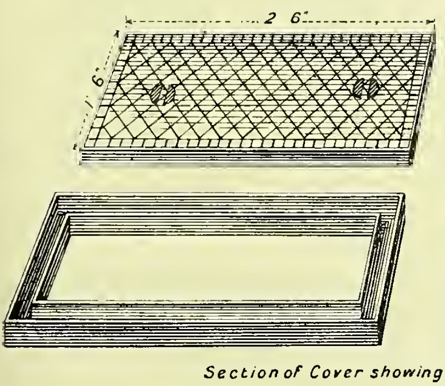


FIG. 440.

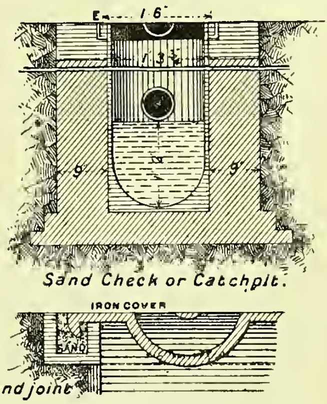


FIG. 441.

Mason's, or Dip Traps.—Mason's, or dip traps (Fig. 442), are sometimes used for this purpose, if connected with foul drains, but they are objectionable, as the point at the joint of the tongue is seldom sound, so that sewer-gas is emitted.

Lowe's.—Lowe's patent trap has been extensively used by the War Department. It is strongly made, and has a hinged grating, so that it can readily be opened and cleared out. The seal, however, rarely exceeds $\frac{3}{4}$ inch, even with the largest size, whilst it very often has practically no seal at all, and it would therefore be advisable to use this trap only in connection with the separate system. Owing to very shallow water level this gully is soon frozen up, and is not to be recommended.

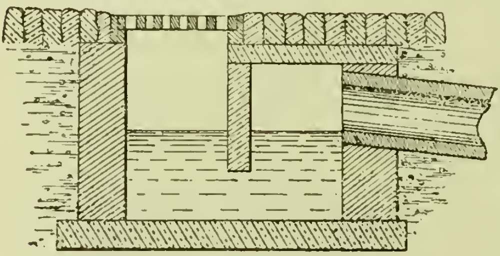


Fig. 442.—Mason's, or Dip Trap.

Fig. 443 shows Stone's improved Lowe's traps; in this description the seal is much improved.

Oates & Green's.—Another form of trap is manufactured by Messrs. Oates & Green, of Halifax (Fig. 444*). The plug is intended to prevent the passage of sewer-gas through the examining eye.

Newton's Street Gully.—Newton's street gully (Fig. 445) is intended to be used in connection with a sewer, and has some advantages.

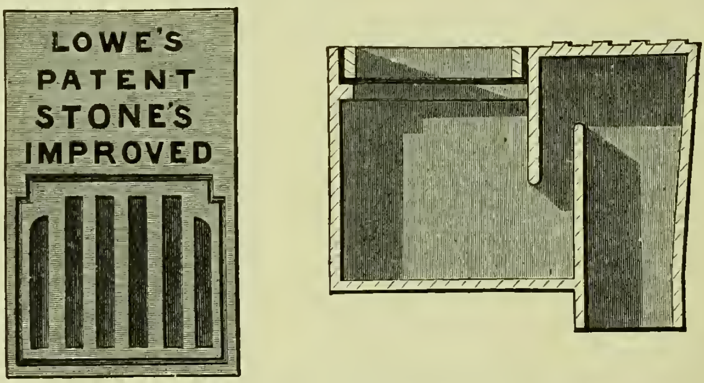


Fig. 443.

Turner and Croker's Gully.—The lift-out gully, shown in Fig. 446, is simple in construction, and does not appear likely to be easily choked. The interior of the trap lifts out, and enables the mouth of the drain to be got at readily, without having to dig up the ground, or spoil any costly flooring. It would, however, soon run dry in dry weather.

* Figs. 444—450 and 453—461, illustrating Types of Gullies for Surface Water Collection, will be found facing page 384.

The advantages claimed for this gully are :—

1. All parts are easily accessible.

2. Cleaning is readily effected.

3. It is easy and simple for disinfecting and flushing drains.

4. Adapted for applying smoke and other tests for defects in drains.

5. Sufficient water seal.

6. Grids prevent unduly large pieces of floating matter from entering the drain, which are so often the cause of their being choked.

It is supplied by the Turner-Croker Sanitary Appliance Co.

Crosta's patent surface-water gully is shown in Figs. 447, 448.

The following are the advantages claimed for it by the patentee:—

1. The gully is so formed as to give a complete double trap, the second trap being independent of the detritus tank, which effectually prevents the escape of noxious gases from the sewers under any conditions, even when the body of gully is empty.

2. The second trap cannot get destroyed by evaporation or leakage, as it is protected from the atmosphere, and there are no joints below the water-level.

3. The bell or shute on the grate conducts all the detritus into the body of the gully, and at the same time protects the second trap, thus preventing the same from being silted up.

4. The gully is so constructed as to effectually prevent the admission of road detritus into the sewers. It also leaves a very small area of water exposed to the atmosphere.

5. By removing the plug in the bend of the dip tube, easy access is obtained to the drains.

6. Every part is easy of access by simply removing the grating.

7. The gully is self-contained, and made in metal sufficiently strong to withstand the heaviest traffic.

8. It is speedily and cheaply fixed, and is so constructed that the upper parts—namely, the grate and bearing for grate—which may be subjected to heavy wear, can be renewed without disturbing the body of the gully.

9. The gully can be fixed at varying distances from the street surface to miss pipes or other obstructions.

10. The capacity is not limited. Any size can be made to suit circumstances.

11. Being made of impermeable material, it cannot become foul by absorbing offensive matter, therefore will not give off dangerous exhalations during long dry seasons.

12. It is an effective preventive against cholera, fevers, diphtheria, and other zymotic diseases so frequently contracted from defective gullies.

13. The ultimate cost (with all special advantages) is less than any other gully of similar capacity.

It is supplied by the Patent Gully Co., Ltd., and manufactured by Mr. George Jennings.

Cartwright's Stench Trap.—Cartwright's self-cleansing stench trap (Figs. 449, 450) is provided with a movable pan, and is intended to collect all dirt and mud passing through the lid.

The trap is strongly made of cast iron, with hinged lid, and is specially designed for flushing from a water-cart or hose.

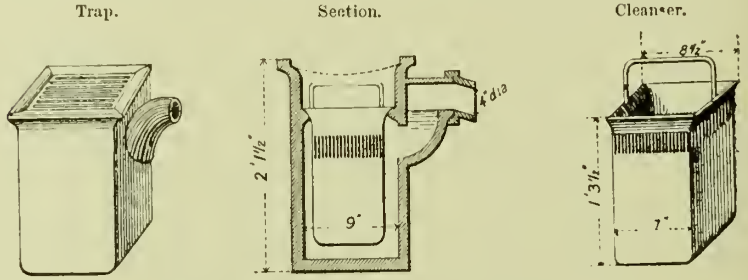


Fig. 451.—Hagen's Cesspool Trap and Cleanser.

Hagen's Patent Duplex Cesspool Trap and Cleanser.—The above pattern (Fig. 451) has the advantage of having a bucket to retain the sand, etc., for cleaning out.

Dean's Trap (Fig. 452).—This trap is provided with a movable bucket ; it is simple in construction.

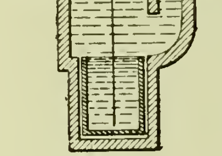


Fig. 452.—Dean's Trap.

The "Grosvenor" Patent Gully.—This gully (Figs. 453—456) is particularly designed and arranged to take from large buildings, such as barracks, factories, workhouses, etc., the surface water, bath wastes, etc. It has a large receiver R (fitted with removable galvanized iron dirt-box (Fig. 453) if required), which is separated from the trap portion of the gully, so that it may be cleaned out without unsealing the trap. The cleaning-eye (Fig. 454) on the outlet T is an important feature, and is provided to allow of drain rods being inserted to clear away any stoppage, should such occur, between gully and drain. The water seal being well sheltered is not readily evaporated, as the gully is complete in itself ; a brick pit is not required, but if the ground is not sufficiently stable it might be bedded on four inches of concrete. It is made in two sizes, with the receiver 12 inches by 12 inches with a 6-inch outlet, and another with a smaller receiver 9 inches by 9 inches with a 4-inch outlet. It has been adopted by the War Department. The manufacturers are Messrs. Ham, Baker & Co.

Ducketts' Gully.—A section of this gully is given in Fig. 457 ; it is made in earthenware, and has been in use by the Burnley Corporation since 1866.

Fig. 458 is **Lovegrove's patent.** It is very liable to get choked, and is difficult to clear owing to the lip ; it is provided with a flap to prevent the return of sewer-gas when the trap runs dry, but a flap in such a position is not likely to remain permanently efficient, as it may be kept open by any obstruction in the shape of straw, leaves, etc.

Sykes' Patent Street Gully.—This gully is represented in Fig. 459. The advantages claimed for it are that as the water before it can escape has to descend, thus arresting all road detritus, whilst light substances float and cannot enter the sewer. The deep seal is intended to prevent untrapping in the hottest weather, and the outlet being well below the crown of the road, it cannot be broken by steam-rollers. Means of access for cleaning is provided by a screw-plugged inspection eye. The trap is manufactured by the Albion Clay Co., in "granitic stoneware."

Stokes' Gully Trap.—This trap has been designed to provide a ready

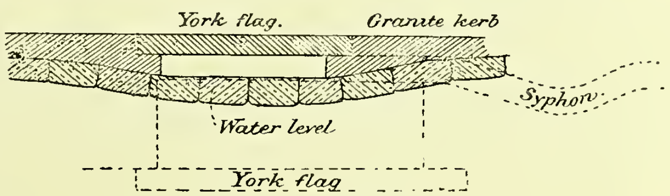


FIG. 462.—"Buddle Hole."

means of access (A, Fig. 460) to the outer side of the trap, so as to clear the drain beyond. It is made by Messrs. Bailey & Co.

Sykes' Patent Yard Gully is shown in Fig. 461 ; it is made by the Albion Clay Co. The advantages claimed for it are, that it possesses a large grate area to take away storm water, with a small surface exposed to evaporation ; its great depth of water seal prevents it becoming untrapped during the hottest weather, its outlet is arranged so as to discharge over a sharp arris, which prevents lodgments of leaves and straw. The gully is provided with an inspection hole fitted with a screw-plug for the purpose of readily clearing the drain. These gullies can be obtained with back or side inlets, or with vertical back inlets to receive rain-water pipes.

There are a great many other traps to be recommended by Clarke, Carlisle, and others.

Buddle Hole.—A "buddle-hole" (Fig. 462) is an opening under a kerb, and is advantageous, as it gives a free and undisturbed water-way, and avoids the necessity for a grating in the street itself.

Liable to become unsealed.—The whole of these traps for letting surface water into a foul drain are sure to become unsealed with any continuance of dry weather, and the only way to prevent it is to send a water-cart round periodically to flush and refill the traps.

A great deal can be done in this way by the judicious application of

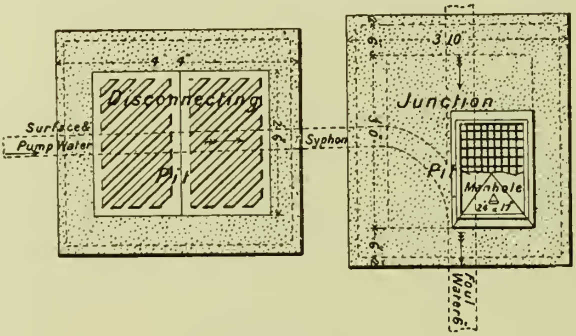


FIG. 463.

some small but constant supply of water as from a pump, but, of course, this cannot be applied on any large scale.

Maintenance of Water Seal.—Fig. 463 shows an arrangement for the admission of intermittent surface water into a drain for foul water, which might be useful in certain cases; the waste pump water maintains the water seal.

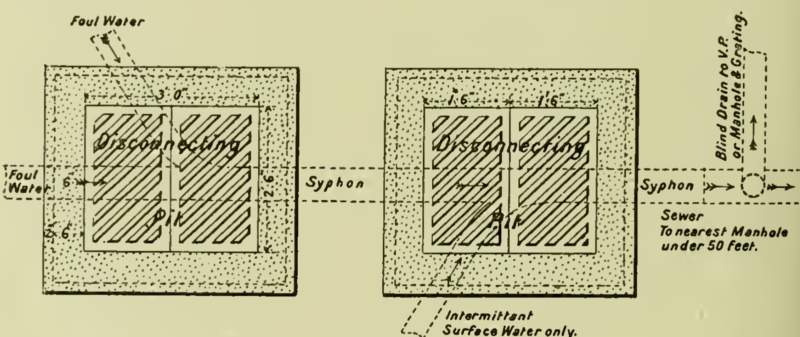


FIG. 464.

Fig. 464 dispenses with the pump waste, the surface water is led into a disconnecting pit with a syphon both at the entrance for the foul water, and also at its exit, the sewage flows through the pit and is only exposed for the short length of channel to the air, and as the pit is covered with a grating there is not much chance of any foul gas finding its way back by the surface water inlet. Independent ventilation of the sewer on either side of the disconnecting pit is necessary.

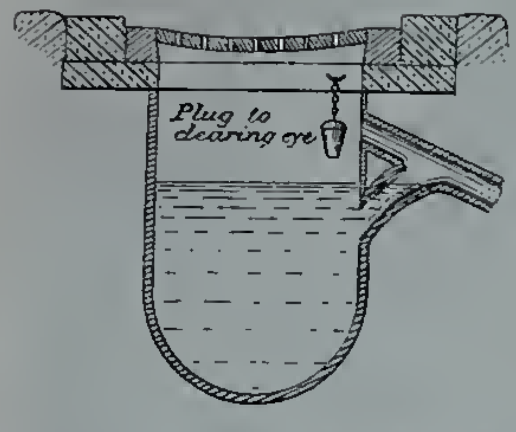


Fig. 444.—Road Gully (Oates and Green).

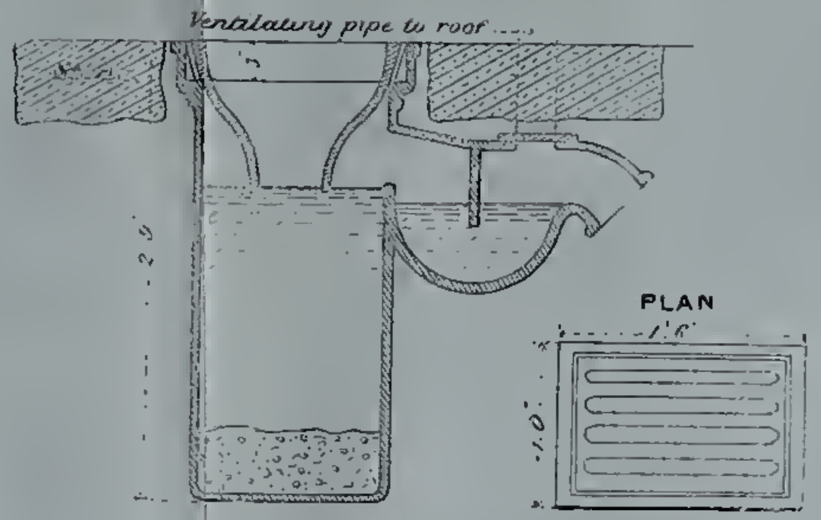


Fig. 445.—Section and Plan of Newton's Street Gully.

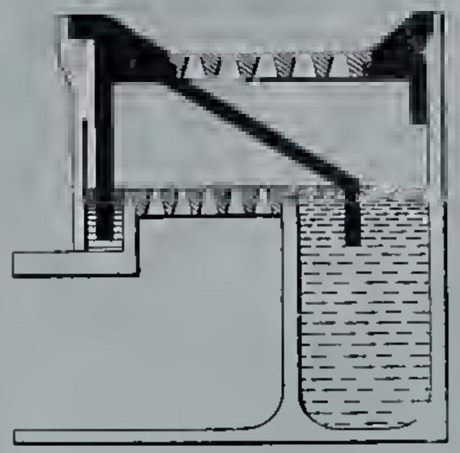
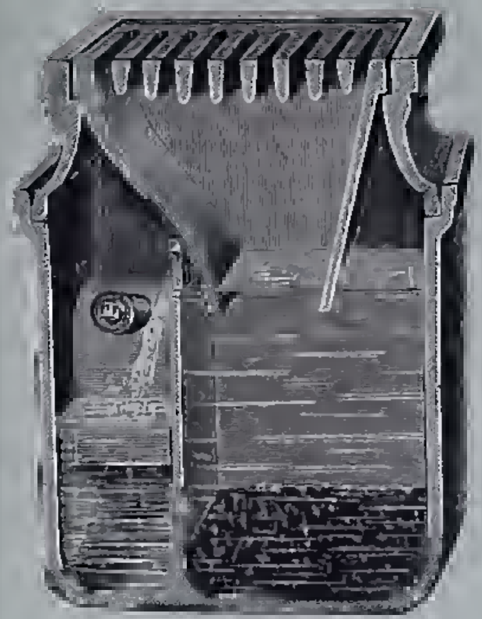
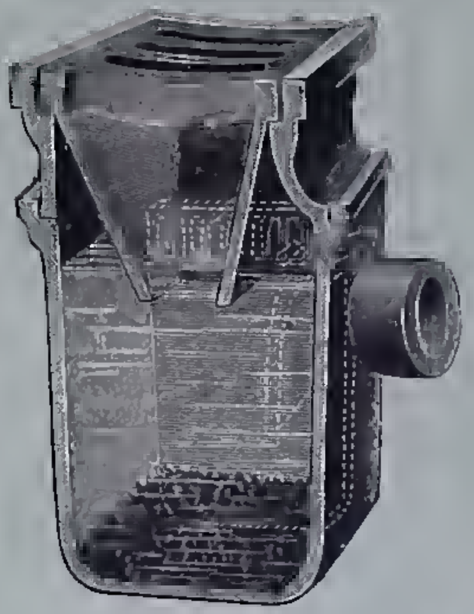


Fig 446.– The Turner-Croker Gully.





Ames and Crosta's Gully.

Fig. 447.– Longitudinal Section. Fig. 448.– Transverse Section.

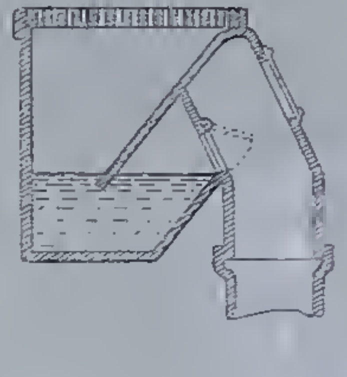
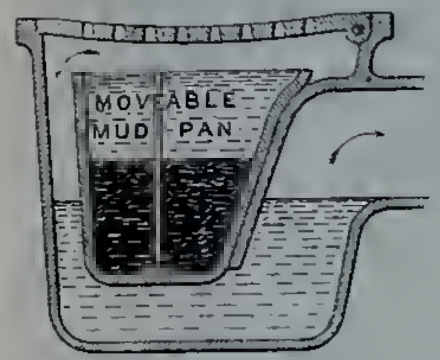


Fig. 458.– Lovegrove's Gully



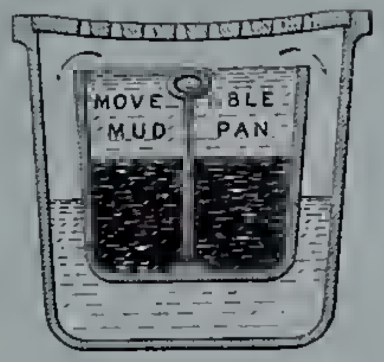
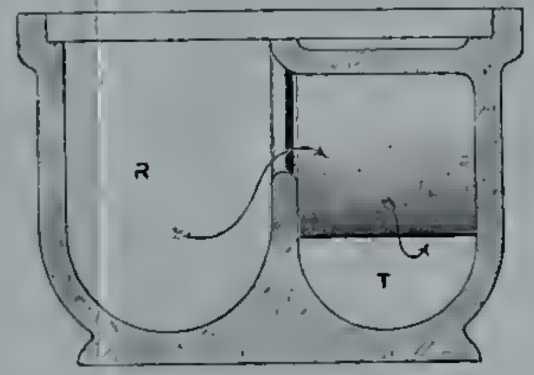


Fig. 449. Fig. 450.
Cartwright's Stench Trap



SECTION A.B

Fig. 454.– The "Grosvenor" Gully

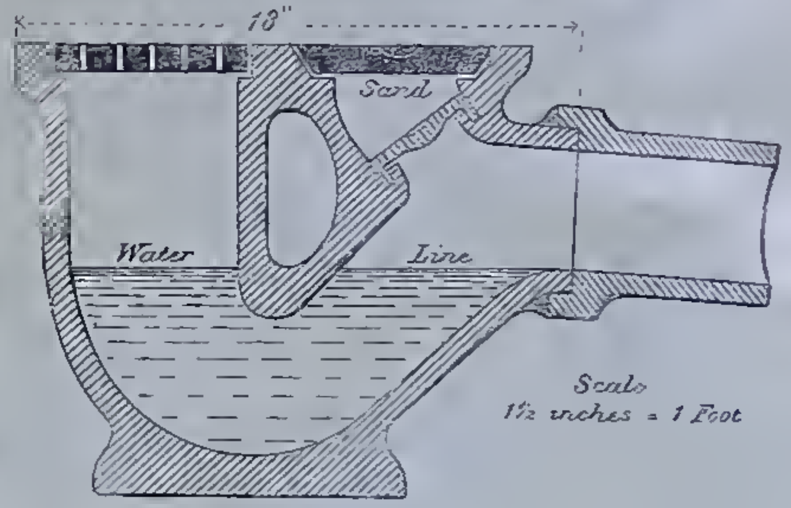
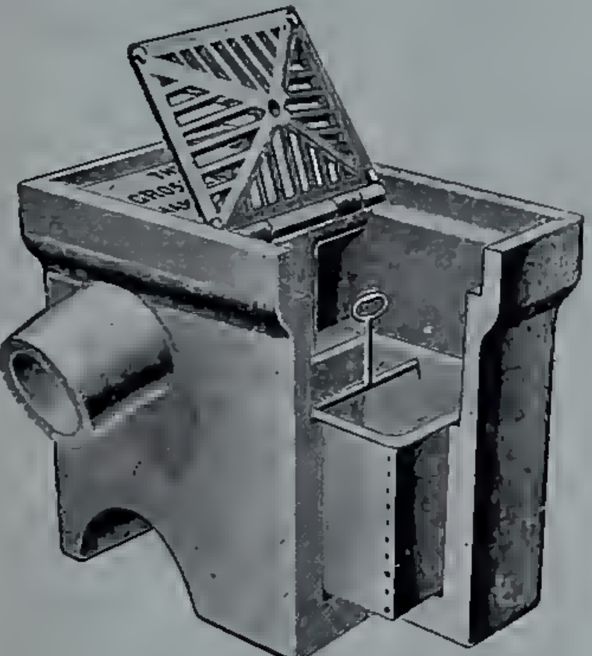
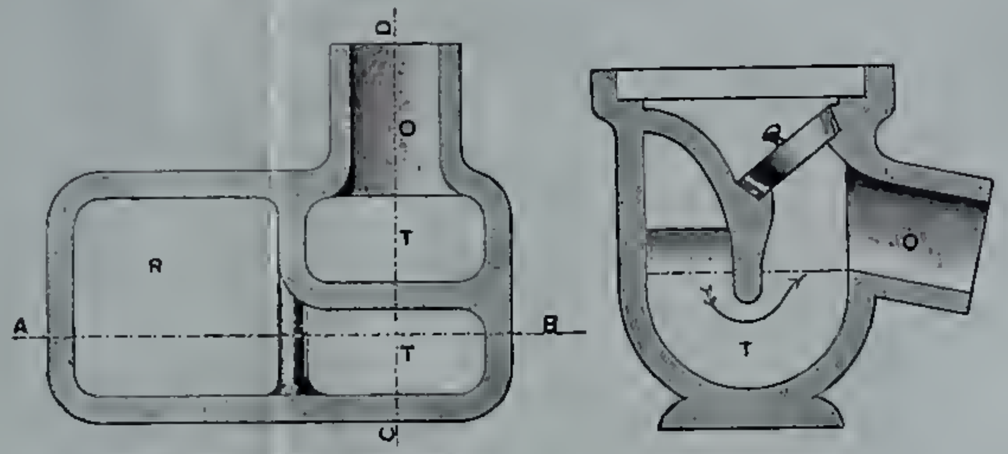


Fig. 460.—Stokes' Gully Trap



F:g. 453.—The "Grosvenor" Gully.



SECTIONAL PLAN OF TOP. SECTION. C.D

Figs. 455, 456.—The "Grosvenor" Gully

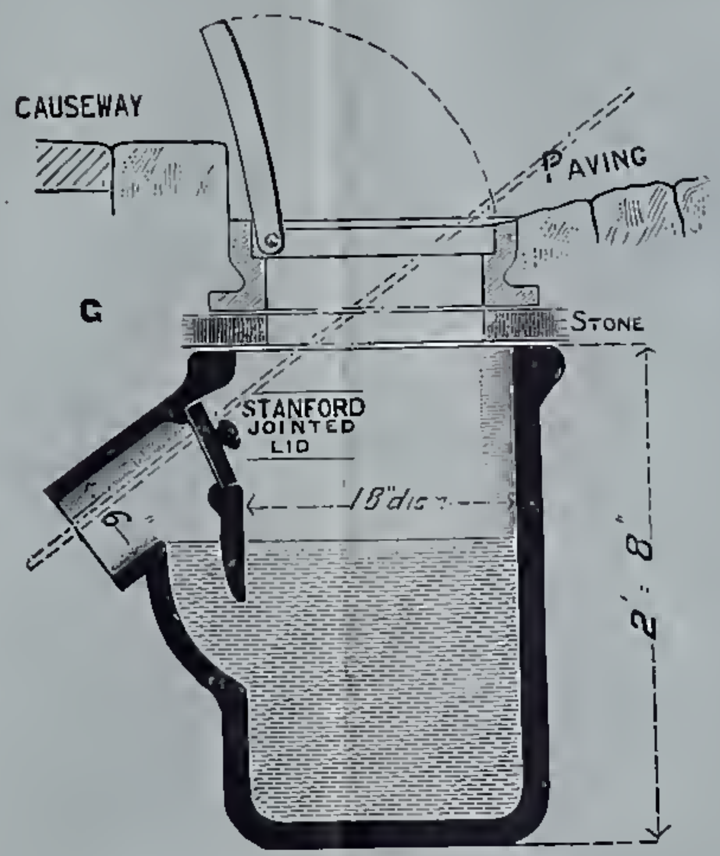


Fig. 457.—Ducketts' Earthenware Gully.

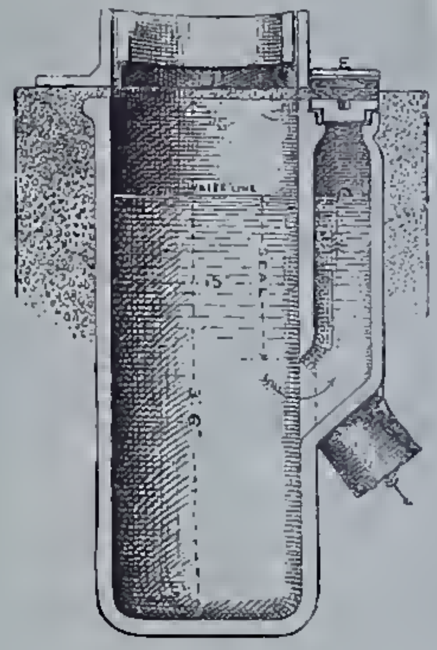


Fig. 459.—Sykes' Patent Street Gully.

Fig. 461.– Sykes' Patent Yard Gully.

CHAPTER XII.

SUBSOIL DRAINAGE.

Source of Moisture.—The principal source of moisture in the soil is rain, and it is only when in excess, so as to become stagnant by retention within a foot or two of the surface, that it becomes injurious. Rain is in itself a source of fertility, but stagnant water is prejudicial, and its removal to a greater depth is desirable.

Injurious Effects of Wet Soils.—Wet soils which retain moisture injure vegetation, in consequence of the extreme reduction of temperature involved by evaporation, and the roots also are damaged by standing in water. If the soil is saturated the warmth of the air cannot penetrate into it, as heat does not descend in water. Wet soil also prevents the circulation of rain-water through the soil, which would be a benefit to vegetation. Wet soils produce a considerable reduction in the temperature of the atmosphere, and are very often the cause of fogs, and such land, when used as the site for habitations, is injurious to health.

Peat and heavy clay shrink about one-fifth their bulk in drying, and swell again in wet weather, so that a building resting on such a foundation is liable to serious injury if not carried below the reach of atmospheric changes.

Subsoil drainage is thus often required to improve the value of land and to secure the stability of a building; in many places also it is a matter of importance on sanitary grounds.

The General Report of the Commission on Improving the Sanitary Condition of Barracks and Hospitals lays down, at page 58, the following principles with reference to sites for barracks:—

"Having selected the site, the whole area within the barrack enclosure should be thoroughly under-drained to the depth of four feet at least, by tile drains placed at distances differing according to the nature of the subsoil and the fall of the ground. The lines of drainage should be closer to each other, or more distant, according as the subsoil is more or less retentive of moisture. In some positions, with a very porous subsoil, in which water never remains, tile drainage may be unnecessary, but such instances are rare exceptions. The drainage should be, in all cases, sufficient to keep the parade ground firm and dry." And with reference to sites for barrack huts, at page 171, it is stated that "A dry subsoil is, in fact, absolutely necessary to health."

The necessity for artificial drainage does not so much depend on the rainfall, or the power of the sun to carry the moisture off by evaporation, as upon the character of the subsoil.

If the subsoil is composed of sand or gravel, or of other porous earth, the greater part passes off by natural drainage below the surface. If, however, the subsoil be of clay, rock, or other impervious substances, the downward flow of the water is arrested, and it sometimes shows its presence in the form of springs. All wet soils may be divided into three classes. 1st. Free soils, from which the water is gradually discharged by percolation through itself, by evaporation on the surface, and absorption by vegetation. 2nd. Peaty soils, which allow the water to percolate, but not so readily as free soils. They have great powers of capillary action, so that a large proportion of water, after being absorbed, is given off by evaporation. 3rd. Clay soils, which are retentive of all the water they absorb until it is relieved by evaporation or vegetation.

Other descriptions of land vary between these classes in proportion to the amount of clay in their composition and their capacity for natural drainage. Each variety requires special treatment for removing the subsoil water, and this is especially the case with retentive clay soils, which are so powerfully acted on by the atmosphere.

The first of these two classes owe, from their nature, their wetness simply to position, and all that is required is to afford an outlet for the water, so as to set it in motion, and thus lower the subsoil water-levels. In the case of high and dry lands, it sinks beyond the reach of evaporation, but it still remains within the reach of atmospheric influence in the case of drained lands, even though it thus stands at a lower level than it otherwise would.

Clays require very careful treatment, on account of their retentive character and capabilities of expansion and absorption. Subsoil drainage makes them permeable, though when the surface is not properly and deeply cultivated their capabilities of absorption are limited, and those of retention and expansion cause them to resist the admission of the rainfall.

Clays readily discharge the excess of water, after a heavy downfall, after their own capacity for retention is satisfied ; on other occasions they give it out gradually.

The retentive nature of clay soils can only be restrained by complete aëration. The drains should exert a powerful influence on the intermediate mass of soil, so as to secure a quick and uniform passage through it for the superabundant water.

Clay is capable of absorbing from 40 to 70 per cent. of its own weight of water.

It should be remembered that drainage of clay soils only alters their condition, and not their constitution. The constant expansion and contraction, as water is absorbed and given off, as well as the retentive power of clay soils, form a marked distinction between them and free soils.

Clay cracks as it dries. It also contains fissures of sand and gravel, and where deep cultivation breaks up the surface, the water finds its way into the clay by these various channels, and thence into the subsoil drains. Atmospheric air follows the water, and as the sides of the cracks are gradually coated with soil carried down by the water, the sides are prevented from sticking together again. The disintegration of the clay soil and the multiplicity of these fissures become greater every year, and consequently the subsoil drainage more effective, as well as capillary attraction to the surface. There is thus evidently a depth suited to each soil to which it is desirable to reduce the subsoil water-level, and beyond which it would not be safe to go in the case of cultivated lands without unduly testing its power of supplying moisture to the plants by capillary action.

Depth of Drains.—There has been a tendency of late years, on account of expense, to reduce the depth of the drains to three feet, but the most eminent authorities concur in considering that the drains should not be less than four feet deep, when the outfall will admit of it. They should be properly executed and so arranged as to secure complete aëration of the subsoil between them, so that although the individual particles of the soil may be moist, it will not retain water.

Many authorities recommend deeper drainage than this, and it is an established fact that the deepest drains flow first and longest. It may be remarked here that in the case of cultivated land, as the surface is never uniform, drains four feet in depth may approach in some places within three feet of the surface, and thus the subsoil water is not kept sufficiently low, and in addition to this, if only three-foot drains are used in the first instance, they may for the same reason come dangerously near the surface, and be disturbed in the operations of cultivation. This would not apply with the same force in the case of subsoil drainage for sites of buildings. Under the latter circumstances it may in some instances be necessary, in order to obtain a fall for the drains, to make them only two feet deep in places. They should then be placed at only about half the intervals at which four-foot drains would be laid.

The contention for shallow drains is really maintained by the question of expense, as the extra foot in depth involves an additional foot of excavation at the top, and is not a mere prolongation of the thin end. The earth also gets harder the deeper we go.

Mains should be placed from three to six inches lower than the minor drains discharging into them, so as to avoid any obstruction which might cause the water to head up into them.

Arrangement of Drains.—It is necessary, in the first place, to ascertain the source of the injurious water, so as to secure a permanent and effective discharge. To do this, the geological formation and dip of the strata should be considered. In some cases, the moisture is due to pervious strata cropping out just over an impervious one, and even underlying it, in which cases, by the judicious use of the augur, or boring tool, to tap the water-bearing strata, in connection with other drainage operations, large tracts of land have been cheaply and effectively drained, with beneficial results, extending to some distance around. This is known as Elkington's system. Numerous test-holes should, under any circumstances, be made to ascertain at what depth below the surface the water will lie in wet seasons. The natural drainage by hollows and valleys should be studied and retained as the proper course of drainage, though the future conduit is to be below the surface. Close attention must also be paid to the variation in the inclination of the surface, as well as in the nature of the soil. Relief drains should be applied at all changes of planes to those of smaller inclination, so as to avoid the impediment caused by the slower flow of the flatter drains.

It is thus seldom that the drains can be laid uniformly parallel to each other, but they must be arranged to suit each portion of the ground. The minor drains must be of sufficient size to carry the total maximum amount of water that may flow through them without pressure, as otherwise it would wet the land through which it passes without draining it.

The size of the mains should be calculated to carry away readily the water to be collected from the minor drains. In each case proper allowance should be made for the inclination of the pipes.

Fall.—When the general surface of the ground is nearly level, very little fall need be given to the drains. When practicable, it is well to have a fall of not less than 1 in 100 ; more is preferable, but as little as 1 in 400 is sufficient if the drains be very carefully formed. It will, however, be usually found less expensive to make a fall of 1 in 200 rather than 1 in 400, as the latter requires extra care in forming it. A very steep slope is objectionable, as the flow of water tends to injure or obstruct the drains. With steep slopes it is desirable to place the drains at less intervals than with ordinary slopes. Stone drains require a greater fall than tile drains, as the water does not pass through them so easily.

The fall should be uniform, or of increasing descent, towards the outfall, to avoid deposit of silt, as particles which would be carried along the pipes at a good fall might be deposited when the flow of water is lessened owing to the reduction of the fall in the drain. Where an alteration of fall to a decreasing rate of fall must be made, a silt basin should be placed to catch the deposit.

Distance between Drains.—Under similar conditions the distance apart should be in inverse proportion to the rainfall, so that the maximum amount may be freely absorbed and discharged at all times. It may be made to depend upon the depth of the drains in free soils, but clay soils must be considered independently, the maximum distance in the latter case being 27 feet, and in some cases they may have to be placed from 21 to 24 feet apart. In strong loam they may be placed as far as 30 feet apart, in light soils, 40 feet apart ; the intervening ground will then be effectively drained, the level of the water in the ground between being somewhat as indicated in Fig. 465. In gravelly soils, drains may be laid at greater intervals than 40 feet, but they should then be deeper than four feet. In good clean gravel the drains may be dispensed with. In every case, however, due regard must be paid to the continuance of humidity of the atmosphere, and to the character of the soil.

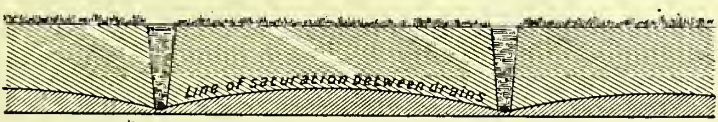


FIG. 465.—Distance between Drains.

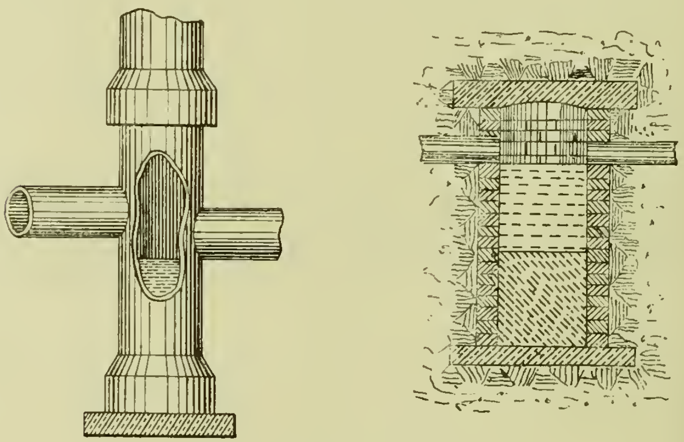
In the case of a steep slope terminating in a flatter one, with soil of the same character, the soakage from the hill will necessitate a greater number of drains on the lower land than on the higher.

Direction.—The minor drains should follow the line of greatest descent, and it is evident that when laid at right angles to the mains, and so parallel to each other, that the shortest possible drains are obtained in land that admits of uniform drainage. They thus share the work done uniformly. In ploughed land they very often follow the furrows when straight, or nearly so, instead of crossing the ridges, as they should do if the plan of parallel equidistant arrangement were strictly adhered to, and this plan should always be adopted in grass land, unless there is a probability of its being broken up, flattened, and laid down again. Where drains are laid across the fall of the land, water escapes from them in its passage. If the work stops on a slope, a cross drain, called a header, should be introduced, connecting the tops of all the minor drains, so as to cut off the water passing down the slope in the subsoil between the pipes.

An open drain is useful on a gentle slope to cut off the surface water flowing from the upper portions, and would be more effective than an under drain. Sometimes it is necessary to use both the header and the ditch. The direction of the mains may have to be modified, so as to increase their discharging power if, from motives of economy, it is undesirable to use a larger pipe. With this object in view, two separate mains are laid on each side of the hollow, and the inclination increased by running the head of each upwards into the rising ground.

It is objectionable to use long main drains, especially with a low gradient, as they check rapid action in the system. When they cannot be avoided, wells, or sumps, with overflow pipes into some convenient ditch, should be introduced into the line of drain to relieve the pressure.

Outlets.—The outlets should be carefully chosen, and should be as few as possible, consistent with a proper allotment of the lengths of the



Figs. 466 and 467.—Silt Basins.

mains. An average of about 14 acres to one outlet appears to be the usual practice. The outlets should be composed of iron pipes, set in masonry, and discharge with a drop of a few inches into a watercourse. Care must be taken that the outlets do not get stopped up, and that they are at such a level that there is no probability of water being forced back through them during floods. A flap is sometimes used for this purpose, as shown in Plate XXIX., which gives the details of the work required in connection with outfalls for either a small or large system of drainage. An iron plate, with the date and number on it, should be let into the masonry, and entered on the drainage plan. The site of all the drains should be correctly shown on the plan.

Silt Basin.—Silt basins should be formed on mains at junctions where there is likely to be a great flow of water, or at the foot of an incline in the drain, where there is a change of the fall to one less steep. They

Fig. 1.

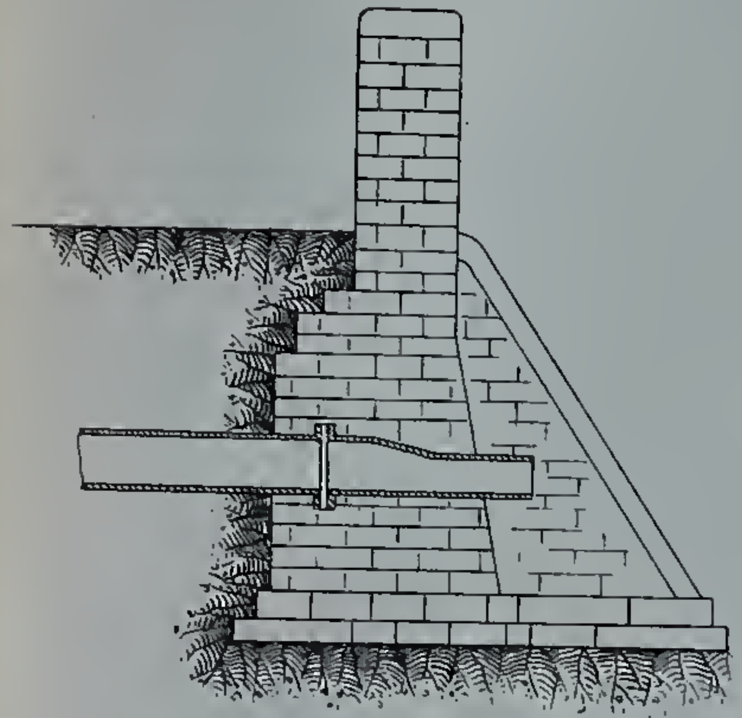


Fig. 2.

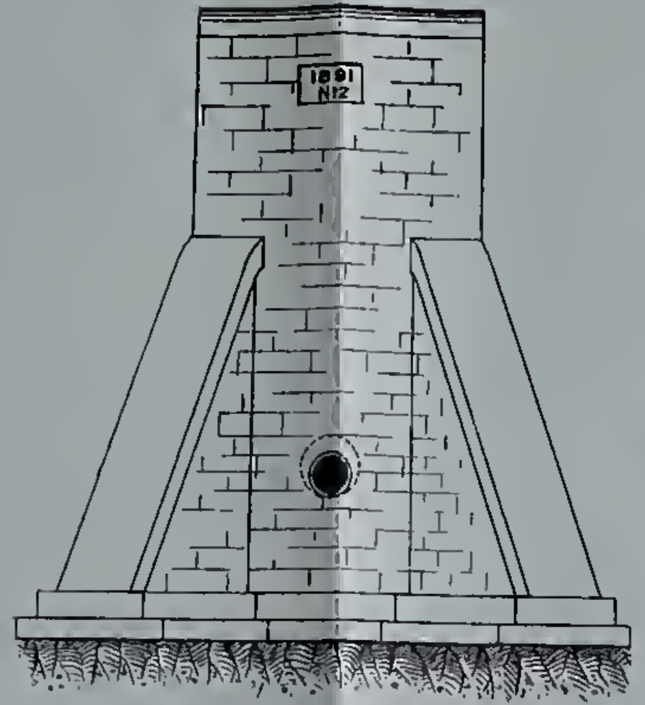


Fig. 4.

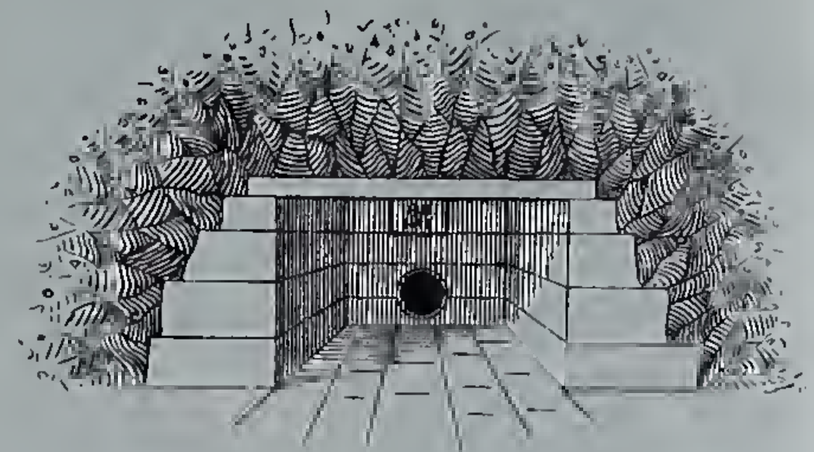


Fig. 5.

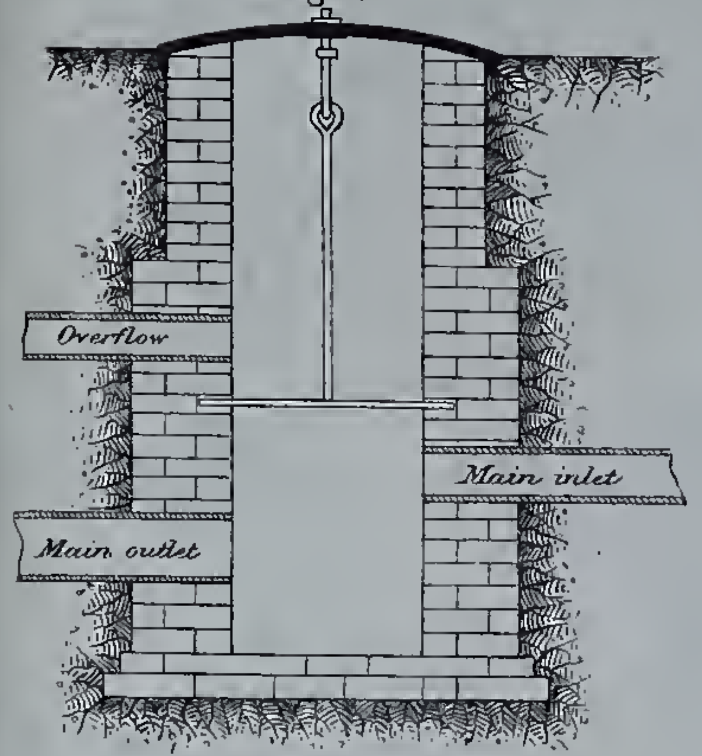
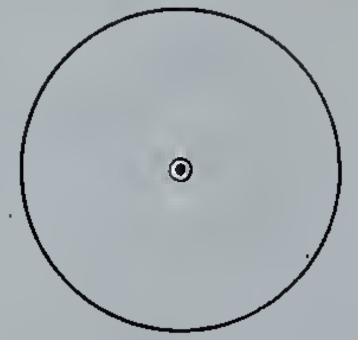


Fig. 6.



Plan.

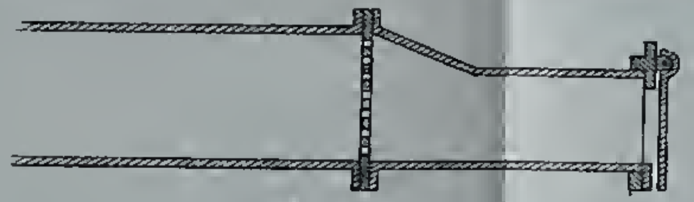


Fig. 3.

Fig. 8.

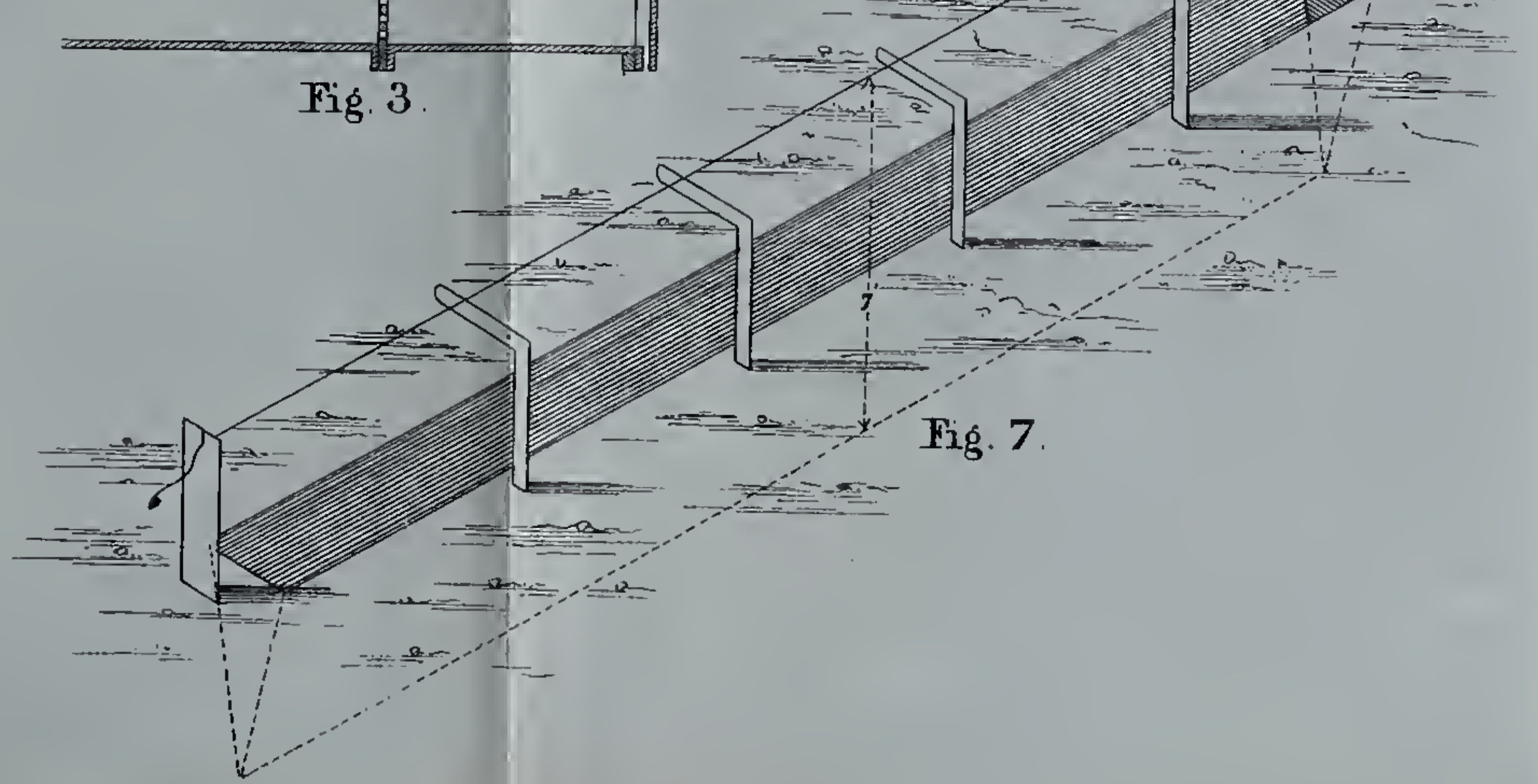


Fig. 7.

J Akerman Photo-lith London

may be formed of brickwork, or with a large pipe on end, or with a wooden barrel. They will last many years without being filled up, and then they can be cleared out. Figs. 466 and 467 show ordinary forms of silt basins.

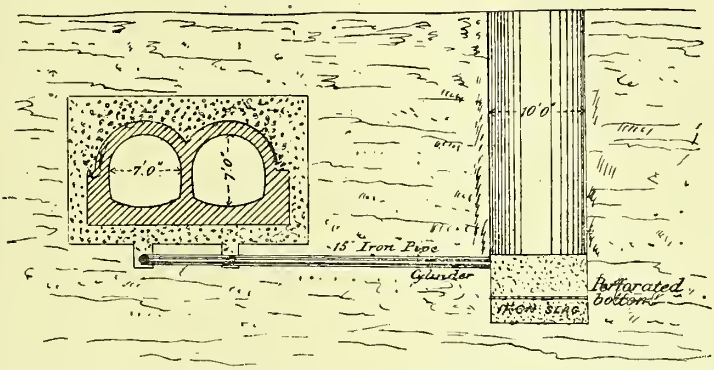


FIG. 468.—Method of Draining the Subsoil Water from the Exterior of the Sewers.

Wells, or silt basins, at proper intervals, are very useful for observing the flow of water in the drains, and thus it may be readily ascertained whether the drains are free from obstruction and are acting properly.

Sumps: Use of.—Where it is necessary to drain below natural out-

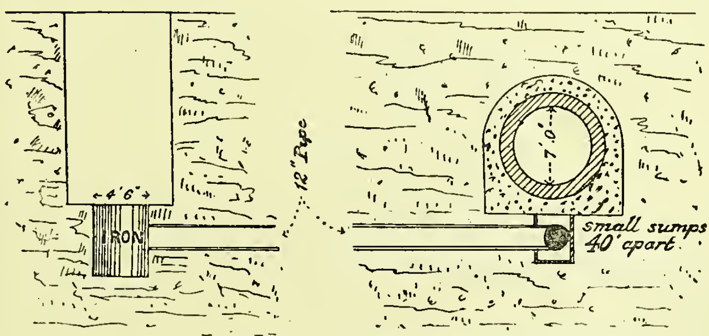


FIG. 469.—Method of Draining the Subsoil Water from the Exterior of the Sewers.

lets, such as on sites only a little above high water level, the water may be carried into sumps or wells, from which it can be passed off by pumping, or by valves, to let it run out at low water.

To prevent the subsoil water forcing its way into sewers, drains should be laid to carry it off. Figs. 468 and 469 show the method adopted in the Main Drainage Works of London to drain the subsoil water from the exterior of the sewers.

Flushing.—It may be advantageous in some cases to provide for flushing the mains from a stream, or by retaining water from drainage by means of a supply pipe and well with a water-tight flap.

Air Drains.—An increased rapidity of discharge from a long main drain, or one of slight inclination, is obtained if air is admitted directly to it, and an air drain connecting the upper ends of the minor drains has also been advocated. Such contrivances would apparently be advantageously employed in the case of the denser clays, but this would not obtain with porous soils.

Clay Soil.—The worst ground for a site is a clay soil, or a clay subsoil, coming near the surface ; but the disadvantages will be reduced to a minimum, if not entirely removed, by efficient subsoil drainage.

It is desirable that the subsoil drains should be below the level of the

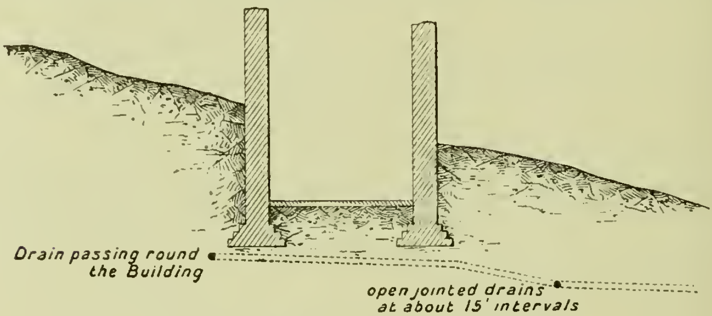


Fig. 470.—Drainage Underneath a Building.

footings of the walls of a building, and that they should lead away from it without passing under it.

Drainage under Foundations.—It may be necessary in some cases to lay drains under foundations, in addition to the ordinary subsoil drainage, to guard against *water from below rising* into them. Such drains should be laid with a considerable fall into the adjacent subsoil drains, or the water from them should be carried away from the site by an independent drain ; they should not form any part of the main system of drainage of the site, so that in case of any stoppage of a drain underneath the foundations, no water could find its way under the building from the surrounding drainage.

Buildings.—Magazines.—This becomes of importance in the case of a building on the side of a hill, as in Fig. 470, and for magazines placed below the ordinary surface level, as in Fig. 471, where floors and walls must be kept perfectly free from damp.

Surrounding Site.—It will be found a great advantage to put in subsoil drains surrounding the immediate site, if possible, to a depth below the footings of a building, before making excavations for the foundations, as the water will thus be prevented from running into the trenches.

Special for Footings.—If the excavations are carried below the depth of the subsoil drains, it will be desirable to drain them separately by

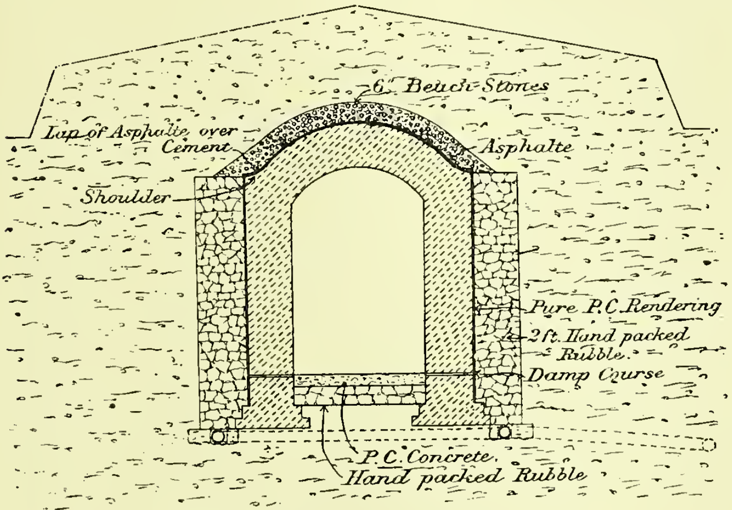


FIG. 471.—Drainage Underneath a Building.

carrying off the water to a lower level. In special cases this may not be possible, and it may be necessary to leave the site undrained, building in below ground with hydraulic mortar or cement, and afterwards

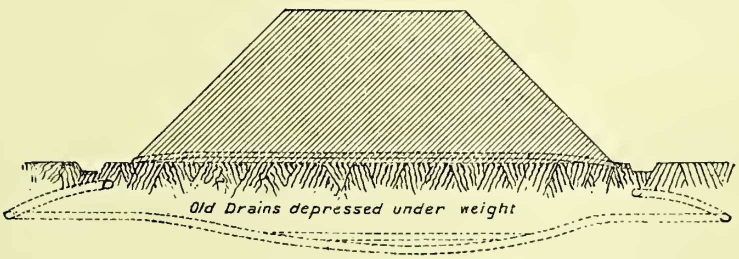


FIG. 472.—Section through Railway Embankment, showing Depression of Drains.

draining in the ordinary way around the building. In such a position the subsoil water may be kept out of the trenches by sheeting and puddling, if it cannot be kept under by pumping.

Where the subsoil drains are not below the level of the foundations, the whole area under the building, and above the level to which the drainage is laid, should be covered with a layer of concrete.

For Peaty Soil.—In ground of a peaty nature it is essential that, if it be drained at all, the drains should be laid before the work is commenced, as such a site is seriously affected by the drainage, and the substratum becomes easily compressible.

Railway Embankment.—When any great weight of earth, such as a railway embankment or a parapet, is to be placed on a site which is already drained, the drainage should be made independent on each side of the site and lead outwards from it and clear of it, as shown in Fig. 472, to ensure the proper drainage being maintained, and to avoid the risk of the drains under the embankment being stopped up by the compression of the soil under the superincumbent weight.

Drains through Foot of.—It is often advisable to lay open-jointed drains at intervals through the foot of an embankment near the natural surface of the ground to carry off the water which may sink into the made earth, and might cause it to slip or settle; and with retentive soil, it may be necessary to insert drains on the top and down the faces of the embankment to prevent its slipping. When it is required to carry any part of the drainage underneath the embankment, a small culvert should be formed, or a pipe drain jointed in cement carefully laid should be provided, in order to avoid the risk of any accumulation of water underneath.

Execution.—All works of drainage must be laid out with great care, and executed completely and efficiently. Any defects are likely to be of serious consequence, and are usually difficult to remedy. The laying out of the work should be prepared upon a plan and then marked upon the ground. It will be necessary to decide upon the whole extent of the work to be done, including the position of the outlet, the direction of the mains and branch drains (or laterals), the depth, intervals apart, and the sizes of the pipes. On a proper adjustment of all these, economy and efficiency will depend. The consideration of the means of getting rid of subsoil water before putting weight upon the ground is very frequently neglected, the result being damp walls, unequal settlements, as shown by cracks in a building, and sometimes sliding of embankments.

Trenches, Depth of.—The trench for a subsoil drain is usually from three to six feet deep, and is cut as narrow as possible for the depth.

The amount of excavation for the required depth will depend a good deal upon the skill of the excavator, and upon the nature of the soil. The bottom need only be sufficiently wide to take the pipes, provided the excavation can be laid without the workmen having to stand in the trench. The tops will be from one to two feet wide, and the sides sloping, as shown in Figs. 473, 474.

Ordinary Tools.—Machines.—It will generally be found more economical to let the workman make the trench of the width he can conveniently manage, rather than insist, in every case, upon a very narrow trench. Many special forms of spades and scoops are made and recommended to be used in digging trenches, but workmen will rarely be found to use with advantage tools to which they are unaccustomed. But narrow spades and scoops, as Fig. 475, should, if possible, be used for excavating and finishing off the bottom of the trenches to the required fall. Tools for this purpose are made in a great variety of shapes; some of these are given in Figs. 476—484. Fig. 485 shows the method of laying the pipes in the trench by means of the tool in Fig. 482.

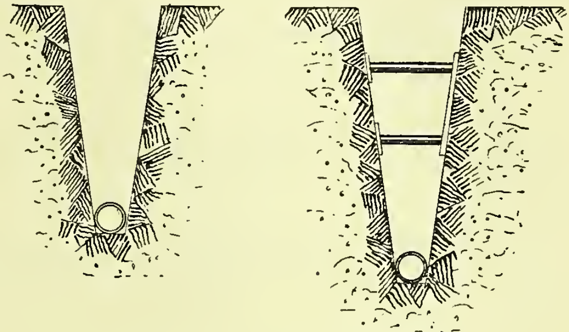


FIG. 473. FIG. 474.
Trenches for Subsoil Drainage.

Machines.—Special excavating machines, worked by steam power, are used to cut the trenches for draining extensive areas.

Bottom to be Currented Accurately.—The bottom must be currented with great accuracy (*vide* Plate XXIX., page 390, also page 219), every part being tested with boning rods. Where the soil is very loose or formed in running sand, the bed for the pipes should be formed with a layer of stiff soil or clay. This will not, as might be supposed, stop water rising into the pipes, as after a short time it becomes quite porous.

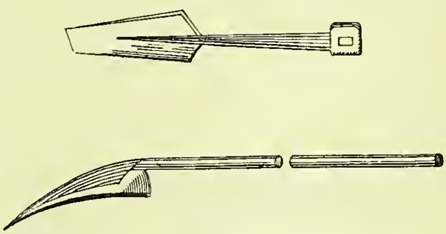


FIG. 475.—Tools for digging Trenches.

Pipes.—Material and Size.—The pipes in general use for subsoil drains are circular, though several other shapes used to be manufactured. They are made of clay similar to that used for ordinary bricks, and are burnt in the same way as bricks. Those from one to two inches diameter are usually made in lengths of 12 to 15 inches. The 1-inch pipes are not reliable, and are now seldom used. The 2-inch pipes are generally used for minor or lateral drains, up to 16 chains in length. For larger drains, 2½ or 3-inch pipes should be used at the lower parts. Collars are sometimes made to encircle the joints of pipes, but they are seldom used on account of the increased expense. They are

Fig. 476.

Fig. 477.

Fig. 478.

Fig. 479.

Fig. 480.

Fig. 481.

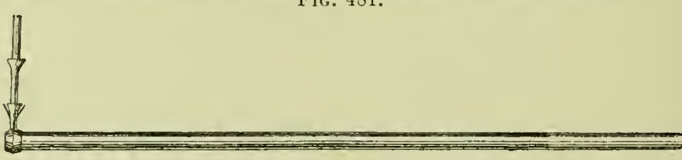


Fig. 482.

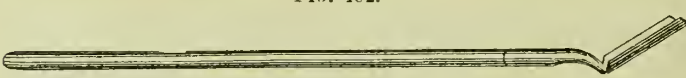


Fig. 483.

Fig. 484.

Figs. 476—484.—Tools for Excavating Trenches for Subsoil Drains.

valuable in preserving the continuation of the drain, but in the case where pipes of smaller bore than two inches would be used, the increased difficulty of preserving the continuity is got over by not using any pipes under two inches diameter of bore. Their use would be advisable in

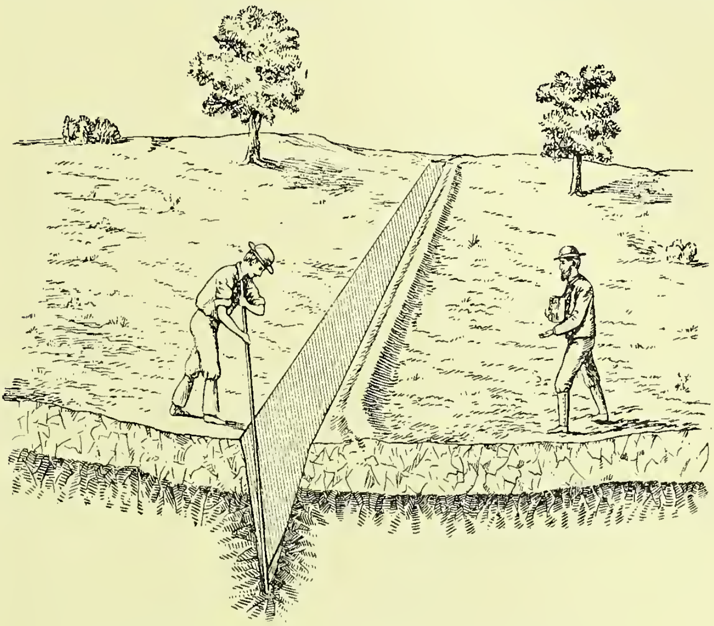


FIG. 485.—Application of Special Tool in laying Pipes.

sandy soil, to check the tendency of the pipes to become choked with silt. It has been found by experiment that by far the larger part of the water enters the pipes through the joints, and only a small percentage percolates through the pores of the pipes. The pipe and collar are shown in Fig. 486. Larger sizes of pipes are used for main and cross drains, into which a number of the smaller drains run, or for draining places where a large accumulation of water may, at times, have to be passed off. Sizes over 2 inches diameter are generally made in 2-feet 6-inch lengths.

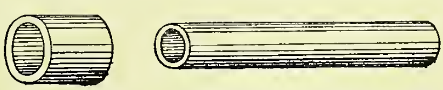


FIG. 486.—Round Tile Pipe and Collar.

From the conditions already given for mains, they should apparently consist of the ordinary glazed stoneware socket pipes with joints set in cement.

Quality.—The pipes should be hard burned, and give a clear ring when struck. They must not be warped or out of shape by over-burning.

Exactitude of form is even of more importance than smoothness of surface. One bad pipe may destroy a long length of drain. It is well to order all pipes to be delivered by the contractor who is to supply them, so that he may have the risk of carriage ; all broken and inferior pipes to be rejected. Badly burned pipes are very brittle, so that the cost of carriage of broken ones would be considerable if an inferior lot are supplied. Only round pipes should be used ; other shapes are still sometimes made, but they have been proved to be much inferior to the round pipe. However, any kind of pipes are better than stone-packed drains.

The following Table shows the number of rods in length and the net number of pipes required per acre, with drains at various distances apart :—

TABLE 78.

Distance between the Drains.	Rods ($5\frac{1}{2}$ yards) per Acre.	Number of Pipes in Lengths of			
		12 inches.	13 inches.	14 inches.	15 inches.
Feet.					
15	176	2,904	2,680	2,489	2,323
18	146	2,420	2,234	2,074	1,936
21	125	2,074	1,915	1,778	1,659
24	110	1,815	1,676	1,555	1,452
27	97	1,613	1,489	1,383	1,290
30	88	1,452	1,340	1,244	1,161
33	80	1,320	1,219	1,131	1,056
36	72	1,210	1,117	1,037	968
39	67	1,117	1,031	957	893
42	62	1,037	958	888	829

Junctions.—Where a drain is joined on to the main drain or cross drain, it should be laid with an oblique junction and a special Y junction used. These junctions can be obtained of the same make as the pipes, but if there should be a difficulty in procuring them, junctions for socket pipes might be used, but they are much more expensive. However, they are more frequently laid without the special junctions ; in such a case an interval somewhat greater than the external diameter of the side drain-pipes should be left between two pipes of the main drain, a length of pipe of a diameter sufficient to act as a long collar to the adjacent lengths being inserted on the main. The connection should be made by cutting out a hole on the upper side of this collar, with a pointed hammer, to receive the end of the tributary drain-pipe, which must be trimmed off to correspond with the inside surface of the larger pipe to which it is to be joined, as shown in Figs. 487, 488, so as to cause no obstruction.

Laying.—The pipes are butt-joined, and are laid dry in the bottom of the trench ; the adjoining ends should be placed close together, and in all cases it will be found that the uneven faces of the butt ends leave the joints sufficiently open, so that any water coming into the trench can find its way into the pipes.

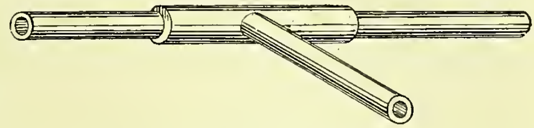


Fig. 487.—Junction.

Method of.—Fig. 489 shows the ordinary forms of the pipes and collars laid, though, as before mentioned, the collars may be generally safely dispensed with.

The bottom of the trench having been carefully finished to the suitable slope, the pipes should be laid by a bricklayer, or some man specially trained to the work, as it cannot be properly done by an ordinary labourer. Work of this nature should never be done on piece-work.

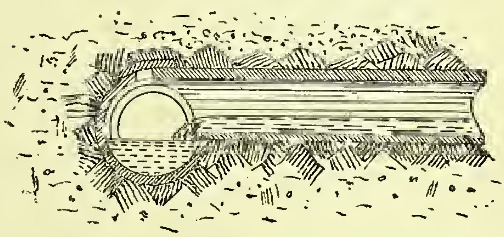


Fig. 488.—Section through Junction (Fig. 487).

It will be found an advantage to lay the pipes as soon as possible after the trench is formed, as water running into it will injure the surface of the bottom on which the pipes are to be laid.

All pipes should be laid resting firmly on the bottom of the trench, so that the filling in of the earth may not disturb the joint. It is well to wedge them against the sides of the trench, or a few stones may be packed around and above the pipes to steady them.

Fig. 489.—Pipes and Collars as laid.

Filling in Trench.—The trench should be filled in soon after the pipes are laid, so that they may be protected from the risk of being disturbed by earth falling on them. The filling in, or " blinding " over the pipe with the first covering, to a depth of three or four inches, should be done by the skilled workman who lays the pipes ; this will avoid the risk of displacement of the pipes by the hasty filling in of the trench, the remainder of which can be done by ordinary labourers.

Stones over Pipes.—There is a difference of opinion amongst men of great experience as to the best method of filling in over the pipes. One way, and that which at first sight appears to afford the best means of drainage, is to fill in over the pipes with stones, as in Fig. 490.

Fine Earth.—The packing in must be done with great care, and no stone should exceed four inches in diameter. The object of the stones is to give the water free access through the interstices between them to the pipes. But the crevices being so large and so numerous, a flow of water in small streams is set up, carrying down the fine particles of the earth into the pipes, in which, as the flow is lessened, they are deposited. For this reason the method of filling in around the pipe with fine earth,

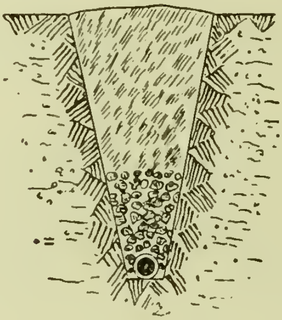


Fig. 490.—Trench filled in with Stones, etc.

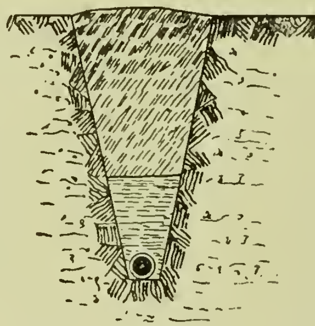


Fig. 491.—Trench filled in with Fine Earth or Clay, etc.

or even with clay, has been found successful, and is recommended. This is shown in Fig. 491.

Sods should be carefully placed round the joints, and fine earth should be filled in lightly for a depth of about fifteen inches; over this the ordinary soil is laid, being at first trodden down and finally well rammed as it comes to the surface level.

Another method is to cover in the pipe with a few inches of gravel or fine earth, and then place over this a layer of compact clay.

Object of.—The object of the fine earth or clay in the first instance is to act as a filter, and to prevent the water flowing in *streams* into the joints, carrying in silt along with it. The clay soon becomes aërated and porous by the water being drawn away from it, and after a time the water will percolate freely through it to the pipes. The layer of compact clay is intended to divert the water from flowing vertically down the trench, so that it may only enter the tiles from the underside, and thus avoid the deposit of silt in them. Drains in which the pipes are surrounded by a stone packing may apparently act more effectively for the first year, as they will carry away the water more quickly at first, but where the compact earth or clay is used, the drains will more thoroughly aërate the soil by the gradual percolation of the water through all parts of it, instead of its trickling down in small streams. Many instances have occurred where pipes surrounded by stones have been silted up in a few years to such an extent as to leave the soil almost entirely undrained. The filtration of water, by means of the surrounding layer of fine earth, is the best safeguard against an accumulation of deposit in the pipes. All roots or fibrous matter liable to decay should be carefully excluded from the earth packed round the pipes.

Stone or French Drain.—In some cases the use of pipes is dispensed with, and instead of them the trench is filled in for about a foot in depth, or sometimes nearly to the surface, with stones from two to four

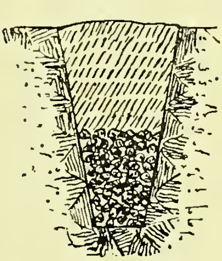
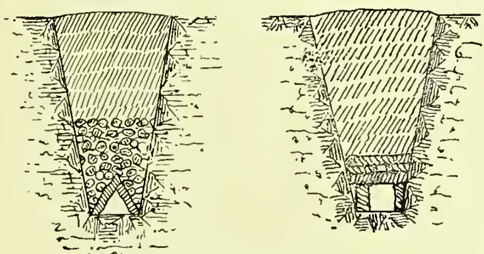


Fig. 492.
Stone or French Drain.



Figs. 493, 494.
Drains formed with Flat Spalls.

inches in diameter, as in Fig. 492. The water finds its way along the trench between the stones. This arrangement is called a *Stone Drain*, or *French Drain*.—Rounded pebbles are better for this purpose than angular stones. Where a number of flat spalls are available, a drain may be formed along the bottom of the trench by laying them as in Figs. 493 or 494, but if the flow of water washes away the bottom of the trench, the stones are liable to fall inwards and close the ducts.

When stones are used without drain-pipes, the trench should be larger in section ; the packing in must be very carefully done ; and they must be covered with smaller stones to prevent loose earth passing down amongst them. Over the stones a sod may be laid, grass downwards, to keep out silt. In consequence of the amount of labour required, these drains are more expensive than those with properly laid pipes, and are, moreover, very liable to become obstructed.

Hand Packing.—A dry packing of stones in embankments, at the back of revetment walls, or in the foundation of roads, is frequently used with advantage to facilitate drainage.

Brushwood.—Drains are sometimes formed with brushwood, pieces of wood, or sods, as a means of getting rid of soakage water. In exceptional cases, when tile pipes are not available, these substitutes may be advantageously applied. All such drains must be regarded as *make-shifts*, very inferior to tile drains.

Boggy Land.—Wet, boggy land is very troublesome to drain properly. It is not often used as a site for buildings, but it may lie near to dwelling-houses, and, therefore, require draining. The ordinary tile draining has, in many instances, proved useless in such cases, because the drains have been laid before the ground was in a fit state to receive them. The drying out of such land is a gradual process, which must be carefully developed. One or more deep, open ditches should be dug along the lines on which the main drains will eventually run. They should not be less than five feet deep, and the sides must be at such a slope that they will not be liable to fall in.

Trenches about a foot in depth will then be cut across the surface of the ground at intervals of ten to fifteen feet, with a good fall to the open ditches. As the soil dries and consolidates, these trenches are gradually deepened, the bottom being frequently cleared out to allow an uninterrupted flow of water through them. When they have been made to a depth of about two feet, if the ground is drying well, it may be possible to dispense with each alternate drain, deepening the others by degrees to a depth of four feet, and keeping them open till they have been proved to work satisfactorily, and the ground has become fairly firm ; then, but not till then, pipes may be laid. It will be as well to use collars for the pipes, as the bottom of the trench will probably be rather soft, and 2-inch pipes should be used.

Failure of Drains.—Every precaution should be taken to prevent obstructions occurring in drains. If properly constructed, they should last for fifty years without requiring to be re-laid. In low land, however, when the soil is composed of fine materials, it frequently happens that the pipes have to be taken up and re-laid after about ten years, and in peaty soils this may be necessary after three or four years.

The chief causes of obstructions are *silt*, *vermin*, and *roots*.

Silt.—Silt will be deposited wherever there is slack water, owing to a defect in laying, or to an irregularity in the shape of a pipe, or to a decrease of the fall in the drain.

The entrance of silt into the pipe may be to a great extent prevented by having collars on the pipes, or by covering them with a few inches of gravel or other porous soil, and placing over this a layer of compact clay, so that the water may enter *at the bottom* of the tiles instead of at the top, as already mentioned. The deposit of silt in the pipes may be guarded against by the provision of silt basins.

Vermin.—Vermin, such as mice, obstruct the pipes by making nests in them, and dying in them. To obviate this difficulty, and keep them out of the pipes, the outlet openings should be covered with a grating or wire guard, or be protected by packing broken glass bottles around them. The outlets shown in Plate XXIX., page 390, have been used for this purpose.

Roots of Trees.—Roots of many trees, especially willows, will enter pipes, and extend within till they sometimes completely stop up the pipes. However, this difficulty does not occur very frequently. Where it has occurred it has been necessary to take up the pipes and re-lay them. In such cases, when re-laying the pipes, it may be well to provide a double row of them, so that if one gets stopped up the other may escape.

Sometimes it may be necessary to remove the trees for the sake of the drains. Or the difficulty may be got over by making the drains with socket joints in cement through the ground where the roots are likely to extend, say within about fifty yards of the trees.

Roads.—Subsoil drains ought to be constructed under all roads, at intervals of ten to fifteen feet, unless the soil is open gravel, or the foundations have been made up with packed stone. They will keep the road dry, and prevent the surface remaining muddy after rain. It will be less liable to be cut up by the traffic over it, so the expense of draining will be saved by the reduction of the expense of maintenance.

In all cases drainage will be promoted by a judicious formation of the surface, which would be currented so as to prevent any accumulation of water after rain.

Plan of Drains.—The positions of the several drains, outfalls, sumps, and examining holes, should be shown upon the plan of the drainage area. The depths, sizes of pipes, and inclinations at the several places should also be marked upon it. It must be expected that the drains will have to be opened at some time or other, so a proper record of them will save much expense in searching for them, and enable an intelligent supervision of every part of the drainage system to be readily maintained, and consequently prompt remedial measures to be taken should any defect be discovered.

Special Measures for Underground Buildings.—When magazines are built underground, or, as in the case of casemates, they are covered with earth, special precautions, in addition to effective subsoil drainage, have to be resorted to in order to exclude damp. With this object in view, the roof of the magazine, or casemate, is usually covered with asphalte, the external shape being arranged so as to facilitate drainage ; the slopes, however, should not be excessive, or the settlement of the superincumbent mass may drag the asphalte down with it, and thus produce cracks. The slopes on which the asphalte is to be laid should be limited to about 30°, and the portion to be so covered should terminate in shoulders, as represented in Fig. 471.

It is best to render all vertical walls and slopes greater than 30° in pure Portland cement, floated with a steel float to a glassy surface ; in fact, the whole of the magazine might be so treated, for, being protected from the action of the sun, the cement would not be liable to crack.

Care should be taken at the junction of the cement and asphalte coverings to provide an efficient lap.

To still further assist in the escape of water, two feet of hand-packed rubble should be built against the external vertical portions of the buildings, and, if procurable, a layer of six inches of gravel is advantageous immediately over the roof—although even here carefully hand-packed spawls are admissible, as asphalte will bear considerable pressure without cracking. Sharp corners resting on the asphalte are, of course, most objectionable, and tipping on to it from a height should never be allowed.

Should water find its way into an underground building, it may be excluded by the process referred to at page 175 of *Permanent Fortification for English Engineers*, by Major J. F. Lewis, R.E.

The following is an account of the process, as issued with I.G.F. Circular, No. 553 :—

Colonel Moore's Process for curing Damp Walls.—Portland cement is used as the basis of the system, and is applied to the inside of the building, as a rule in two coats, which are afterwards covered over with a third coating of common hair mortar in the ordinary manner, or the third coating may be formed with either Parian or Keen's cement.

The first coating of pure cement is intended to exclude the damp and prevent any wet, no matter how porous the wall may be, from working through ; but as pure cement induces condensation on its surface, it is necessary to cover it up with a substance which would not promote it ; the third coating is designed with this object in view ; the second coat forms a non-conductor and a connecting link between the first and third coats.

1. **Process.**—Rake out the joints of the masonry carefully and render $\frac{1}{2}$-inch thick in pure Portland cement, leaving a key on its surface.

2. Whilst still green, render the first coat over again with Portland cement and washed sand $\frac{3}{4}$ inch thick, in the proportion of one to three, also leaving a good key on its surface.

3. The last coating of hair mortar, brought up to a surface with putty and plaster in the usual way, should now be applied.

As an alternative, when it is required to paper or paint the wall at once, instead of using hair mortar, the last coating may be hand floated, and set with either Parian or Keen's cement.

N.B.—If it is of importance to finish the work still more rapidly, rendering, floating and setting the walls with Parian or Keen's cement ½ inch thick may be substituted for the second and third coats already detailed, but it would be more expensive.

1. **General Remarks on.—Rules for Guidance in Application.**—The result of experience in the use of this process is that the best results are obtained with hair mortar for the final coating, and that it should always be used when it is intended to whitewash, distemper, or colour the walls afterwards.

2. Parian or Keen's cement may be used with advantage for the final coat if it is intended to paint or paper over it, and the work is of an urgent nature.

3. Parian cement is preferable to Keen's cement for this purpose, as there is always a certain amount of efflorescence with the latter when first applied, which lasts for several days and delays the work.

4. If there be no objection to a rough, gritty surface for the finished work, as in passages, walls of casemates, magazines, etc., the third coating may be entirely omitted ; the second coating being finished with a wooden float, so as to leave the grit exposed ; this gives excellent results.

5. **Advantages of.**—There is no difficulty in application.

6. Houses, etc., may be built on this principle, using it in place of hollow walls, thus effecting a saving in the cost of construction, and at the same time affording a much more complete protection from damp than is obtainable by the system of hollow walls, for the damp-proof lining can be brought close up to the door and window frames and tucked in round them, so as to effectually exclude the damp at all points, the only care required being to set all the masonry at the junction of the cross walls with the outer walls in cement, so as to preserve the cement envelope intact.

7. When building a house on this system, compared with one built with hollow walls, there is either a small saving of roofing and a corresponding reduction in the width of the outer walls, or an increase in the area of the rooms is effected without additional cost.

8. The process is capable of being used for the purpose of curing buildings which are damp under every circumstance, as the application is to the inside surface of the walls ; consequently walls of buildings which act partly as retaining walls, casemates which are covered with earth, etc., may be made quite dry by its means, without the expense of having to uncover them in order to stop the leaks.

9. Its application will even make the soffit of an arch quite dry,

through which previously the water was running like a shower bath.

10. This process for curing damp walls is certain in its action, and for this reason, and others already given, its application is most economical, the cost of any other method being in some instances almost prohibitive.

11. It is much easier of execution, and it affords a far superior and a cheaper means for the construction of really dry buildings than can possibly be obtained by any other system.

Fig. 495 shows an extreme case in which the water is finding its way into the building, not only from the crown of the arch, but also through

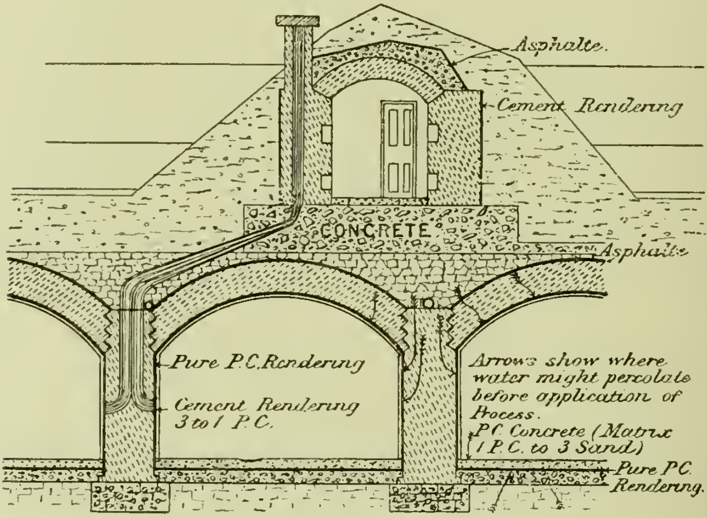


FIG. 495.—Dampness in Buildings.

the floor. It will be noticed that the pure cement envelope is carried over the soffit of the arch, down the side walls, and through the concrete floor, thus effectually excluding the water. It must be intact throughout.

The proportion for the matrix of the upper bed of concrete for the floor must uot exceed the proportions of one pure cement to three of sand.

This system has been employed both at home and abroad with uniform success, having been found in many instances to be cheaper than to uncover and make good defects in drainage and asphalte on the outside, and it must be remembered that time is even of more importance sometimes to a military engineer than cost.

CHAPTER XIII.

SANITARY NOTES.

Made Ground.*—"The surface soil of London, and also of many other large cities and towns, is a mixture of mould, gravel, or clay, with débris of ancient buildings and rubbish. Much of this has been upturned over and over again, so that it comprises an accumulation of brick-bats, fragments of crockery, and what not, commingled with relics of the soil and subsoil. In a few localities in London it has accumulated steadily, or at irregular intervals, at the rate of from six inches to one foot a century. Much of the "made ground" is thus of ancient date, and in these undisturbed areas it has preserved trophies of the Roman occupation, of the Great Fire, and other interesting episodes. Made ground may be from a foot or two to about twenty-five fect in thickness, the greater thicknesses being here and there due to the in-filling of old pits. At the Bank of England there were twenty-two feet of made ground resting on four feet of gravel. Such artificial "soil" of varying character and thickness no doubt extends over the whole of old London. Mr. Whitaker has remarked that Belgravia is probably in great part built on ground of this character, otherwise it would be lower and damper. In itself made ground is not always an unsatisfactory foundation for a house. Much of it, as we have stated, is of an ancient date; moreover, good material may artificially be brought to level an irregular tract. The serious matter is that in these enlightened days it is possible for houses to be erected on pits in which all kinds of rubbish, with decaying vegetable and animal matter, have recently and intentionally been shot. Sir Douglas Galton has spoken strongly on this subject, and he asks, "What, then, can be more dangerous, what more wicked, than the every-day proceedings in the metropolis, and elsewhere, of those persons who purchase a building site, who extract from it the healthy clean gravel and sand which it contains, allow the holes to be filled with rubbish, and then proceed to build upon it?" It is well known that injurious emanations

* *Memoirs of the Geological Survey, England and Wales, Soils and Subsoils*, by Mr. Horace B. Woodward, F.R.S.

come from an impure soil or subsoil, and may rise into a house; so that on such an unwholesome foundation it is absolutely necessary that the basement be securely cemented. The bye-laws of the Local Government Board will, it is hoped, prevent any further building of houses on polluted sites."

Natural Soil.—The natural soil is of varied composition, being primarily derived from the subsoil, which may itself be regarded as the weathered portion of the underlying hard or soft strata. With the decomposed mineral ingredients of the soil is mingled more or less decayed animal and vegetable matter, while the whole soil layer has been largely re-constituted as mould by the action of earth-worms and micro-organisms. Wind-drifted material has also to some extent modified the constituents of soil. As a rule the natural soil is too thin to have any particular effect on the sanitary conditions of a site, although in places it may be as much as three feet or more in thickness. It is naturally thicker on the lower slopes of hills and in valleys, owing to its downwash by rain from the higher grounds. It is usually thicker also on the sandy and loamy areas than on the stiff clays.

"The Influence of Subsoil Water on Health."—Mr. S. Monckton Copeman, M.A., etc., writes in the *Journal of the Sanitary Institute*, April, 1896, as follows:—"A survey of all the recorded work on the influence of subsoil water on health appears then to show that rapid and abnormal oscillations of the level of the subsoil water are particularly dangerous, such variations being of considerably greater importance than the actual distance of the ground water from the surface. Other things being equal, it is doubtless true that the further the ground water from the surface, the healthier will be the site, although in all probability a higher average level without obstruction to the outflow will not necessarily be more conducive to the appearance of disease, so long as the height is not such as to bring about more or less permanent dampness of dwellings.

"As I have already stated, it would appear that with the exceptions perhaps of cholera and typhoid fever, the condition of the upper layer of the soil, as regards the amount of moisture in its interstices, is of more importance than the actual level of the ground water beneath."

Steam, Admission of, to Sewer.—No steam exhaust, blow-off or condensed water from any boiler, or hot water from any manufacturing process (such water being of a higher temperature than 110 degrees Fahrenheit), should be allowed to be connected direct with the sewer or with any drain connected to the sewer—such pipes should first discharge into a tank or condenser, from which a suitable outlet to the sewer should be provided.

Drain Testing.—All drains should be tested before a house is occupied, and afterwards annually, especially if any of the drains run under the building.

An inspector can only ascertain the general design of the drainage arrangements by examining the building; the nature of the workmanship can only be judged by the application of suitable tests.

It is not at all an easy matter to make a reliable inspection of the drainage of a building, and especially so of an old drainage system. In the latter case the examination can never be considered *complete* until every drain, branch, soil, ventilating or waste pipe, has been traced and tested from end to end.

According to the *Sanitary Record*, April 15th, 1893:—"The reliable and successful drain-tester must possess a certain amount of inventive ability and be of ready resource; above all, he must have great patience, and must find out everything for himself as indicated by the tests, and not take anything for granted; and information given to him by those who profess to know should be gratefully received, but at the same time he should satisfy himself of its accuracy and value."

The following description of house inspection more particularly refers to an old house, but the same system, with modification, is of general application:—

House Inspection.—"Sanitary engineers consider that an unusual smell is generally the first evidence of something wrong, and that, traced to its source, the evil is half cured. They inspect first the drainage arrangements. If the basement generally smells offensively, they search for a leaking drain-pipe, *i.e.*, a pipe badly jointed or broken by settlement, and these will often show themselves by a dampness of the paving around. If, upon inquiry, it turns out that rats are often seen, they come to the conclusion that the house drain is in direct communication with the sewer, or some old brick barrel-drain, and therefore examine the traps and lead bends which join the drain-pipes to see if they are gnawed or faulty. If the smell arises from any particular sink or trap, it is plain to them that there is no ventilation of the drain, and more especially no disconnection between the house and the sewer, or no flap-trap at the house-drain delivery into the sewer.

"If a country house be under examination, a smell at the sink will, in nearly every case, be traced to an unventilated cesspool; and, in opening up the drain under the sink, in such a state of things, they will take care that a candle is not brought near, so as to cause an explosion. If the trap is full of foul, black water, impregnated with sewer-air, they partly account for the smell by the neglect of flushing. If the sink, kitchen, and scullery wastes are in good order, and the smell is still observable, they search the other cellar rooms, and frequently find an old floor-trap without water, broken and open to the drain. If the smell be ammoniacal in character, they trace the stable-drains, and see if they lead into the same pit, and if so, argue a weak pipe on the route, especially if, as in some London mansions, the stable-drains run from the mews at the back, through the house, to the front street sewer.

"Should a bad, persistent smell be complained of mostly in the bedroom floor, they seek for an untrapped or defective closet, a burst soil-pipe, a bad junction between the lead and the cast-iron portion of the soil-pipe behind the casings, etc., or an improper connection with the drain below. They will examine how the soil-pipe is jointed there, and, if the joint be inside the house, will carefully attend to it. They will also remove the closet framing, and ascertain if any filth has overflowed and saturated the flooring, or if the safe underneath the apparatus be full of any liquid. If the smell be only occasional, they conclude that it has arisen when the closet-handle has been lifted in ordinary use, or to empty slops, and satisfy themselves that the soil-pipe is unventilated. They, moreover, examine the bath and lavatory waste-pipes, to ascertain if they are untrapped, and, if trapped by a sigmoidal bend, see whether the trapping water is not always withdrawn owing to the syphon action in a full-running pipe. They will trace all these water-pipes down to the sewer, ascertain if they wrongly enter the soil-pipe, the closet trap, or a rain-water pipe in connection with the sewer.

"If the smell be perceived for the most part in the attics, and, as they consider, scarcely attributable to any of the foregoing evils, they will see whether or not the rain-water pipes which terminate in the gutters are solely acting as drain ventilators, and blowing into the dormer windows. They will also examine the cisterns of rain-water, if there be any in the other portions of the attics, as very often they are full of putridity.

"A slight escape of impure air from the drains may be difficult to detect, and the smell may be attributed to want of ventilation, or a complication of matters may arise from a slight escape of gas.

"Neither are all dangerous smells of a foul nature, as there is a close, sweet smell which is even worse. Should the drains and doubtful places have been previously treated by the inmates to strongly-smelling disinfectants, or the vermin killed by poison, the inspectors of nuisances will find it difficult to separate the smells. In such a case, however, they will examine the state of the ground under the basement flooring, and feel certain that there are no disused cesspools or any sewage saturation of any sort. They will also ascertain if there be any stoppage in the drain-pipes by taking up a yard-trap in the line of the drain, and noting the re-appearance of the lime-water which they had thrown down the sink. And invariably, after effecting a cure for any evil which has been discovered, they will have the traps cleaned out and the drains well flushed.

"A thoroughly-drained house has always a disconnection chamber placed between the house-drain and the sewer, or other outfall. This chamber is formed of a raking syphon and about two feet of open channel-pipe, built around by brickwork, and covered by an iron man-hole. Fresh air is taken into this chamber by an open grating in the manhole, or by an underground pipe, and the air thus constantly taken into the chamber courses along inside the drain, and is as continuously discharged at the ventilated continuations of the soil-pipes, which are left untrapped at the foot, or at special ventilating pipes at each end of the drain. This air current in the drain prevents all stagnation and smell.

"When a house is undergoing examination, it is wise to test for lighting-gas leakages, and there is only one scientific method of doing so, which is as follows: Every burner is plugged up save one, and to that is attached a tube in connection with an air force-pump and gauge—the meter having been previously disconnected. Air is then pumped into the whole system of pipes, and the stop-cock turned, and if, after working the pump for some time, and stopping it, the gauge shows no signs of sinking, the pipes may be taken as in safe condition; but if the mercury in the gauge falls, owing to the escape of air from the gas-tubes, there is a leak in them, which is discoverable by pouring a little ether into the pipe close by the gauge, and re-commencing pumping. Very minute holes can be detected by lathering the pipes with soap and water, and making use of the pump to create soap bubbles.

"Besides the drainage, they will, especially if they detect a bad and dank smell, see if it arises from the want of a damp-proof course, or of a dry area; see if there be a wet soil under the basement floor, a faulty pipe inside the wall, an unsound leaden gutter on the top of the wall, or an overflowing box-gutter in the roof, a leaky slatage, a porous wall, a wall too thin, and so on.

"They will also keep an eye upon the condition of the ventilating arrangement, and whether the evils complained of are not mainly due to defects there. The immediate surroundings of the house will also be noted, and any nuisances estimated.

"Sanitary inspectors, whilst examining into the condition of the drains, always examine the water cisterns at the same time, and discover whether the cistern which yields the drinking water supplies as well the flushing water of the closets. They will also ascertain if the overflow pipe of the cistern, or of a separate drinking-water cistern, passes directly into the drain. If the overflow pipe be syphon-trapped, and the water rarely changed in the trap, or only when the ball-cock is out of order, they will point out the fallacy of such trapping, and, speaking of traps generally, they will look suspiciously on every one of them, endeavour to render them supererogatory by a thorough ventilation and disconnection of the drains."*

After making a careful examination of the premises, the best method of testing the drains can be decided on; the most efficient and trustworthy test where it can be applied is the "hydraulic" or "water test."

Hydraulic or Water Test.—This test involves subjecting the drains and joints to a pressure of a head of water of at least five feet. In order to effect this it is necessary to plug the lower end of the drain by means of a drain plug or an air bag, as described below. The most convenient place for applying the plug is at a disconnecting pit or just above the intercepting trap. In order to obtain the necessary head of water a bend and a couple of lengths of pipe on end may be temporarily attached to the upper end of the drain and set in cement, so as to retain the necessary water. A more convenient arrangement is to apply one of Addison's drain stoppers at the upper end also, when the necessary head can be readily obtained by attaching a piece of india-rubber tubing to the brass tube through its centre; the water can be filled in through a funnel.

If no such convenience as a disconnecting pit or intercepting trap exists, the drain-pipe would have to be opened and plugged as already described.

The level of the water should be carefully marked, and any subsidence after a period of, say, two hours, would indicate a fault somewhere, and it would then become necessary to uncover it and examine it carefully.

It is sometimes necessary to test the different sections of a large system of drainage separately. The plugs would then be inserted from the inspection pits or manholes; if there are gullies at various levels they can be similarly plugged if circular in section.

Soil-pipes should similarly be subjected where practicable to the water test, as a greater pressure can thus be obtained which will reveal defects that would pass unnoticed by either the peppermint or smoke tests; but there is a difficulty in its application.

Drain Plugs.—Special drain plugs (Fig. 496) are most useful in connection with drain testing. There are a great many varieties in the

* Parkes' *Hygiene*.

market; the "Addison" patent drain stopper (Fig. 496), manufactured by Nicholls & Clarke, appears to be a serviceable article.

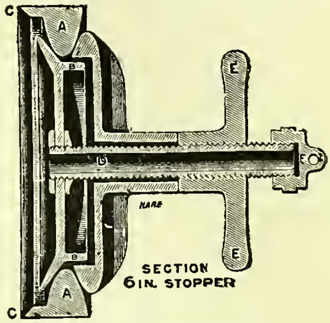


Fig. 496.—The Addison Patent Drain Stopper.

Instead of having a bolt and nut by which to draw up the flanges, a brass tube and nut are used, to which an indiarubber supply tube can be very readily connected for use, either with water, smoke, or other tests.

The rubber ring A is made with a large surface to press against the inside of the pipe, and is provided with a lip C, so that the pressure of water on it tends to make the joints more secure. These stoppers expand about five-eighths of an inch, thus allowing for variations in the sizes of pipes by different makers. The rubber cannot pinch between the two discs, as it is held in position by the guide B. The stopper is fitted with an inside tube D, sealed by a screw cap F, which, when unscrewed, allows the water to escape after being used for testing. The expanding is easily effected by screwing the nut E, which is provided with long wings for the purpose.

They are supplied in the following sizes:—4, 5, 6, 8, 9 and 10 inches.

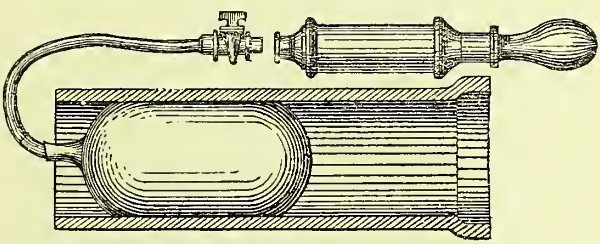


Fig. 497.—Jones' Patent Pipe Stopper.

Jones' Patent Pipe Stopper.—Another patent drain-pipe stopper (Fig. 497), for applying the water test to drains, or arresting the flow when they are under repair, etc., consists of a bag of indiarubber, or some such material, to which is attached a flexible tube with a tap at the end connected to a small hand-pump. The bag is placed in the drain before inflation, and by working the pump it is quickly filled with air under sufficient pressure to dam up the drain or prevent any escape of gas. Turning off the tap causes the bag to collapse, when it can be removed. These bags are made in different sizes to suit various diameters, and have secured the approbation of most leading sanitary scientists.

Peppermint and Smoke Tests.—In the case of old drainage, in order to ascertain whether there is anything defective in the traps, apparatus, or joints of pipes, resulting in the emission of sewer-gas at improper places, the drains should be tested by either the peppermint or smoke tests, which will be found very convenient for the purpose.

Instructions for Peppermint Test.—Carefully close all ventilating pipes from soil-pipes or drains; ventilating shafts from drains; inlets for fresh air to drains, or soil-pipes, etc., by means of a damp cloth or some clay.

Place about a table-spoonful of the crude oil of peppermint in the pan of the topmost w.c., and gradually pour in about a gallon of hot water. If the peppermint makes itself felt inside the house, or in the drain outside, it indicates a defect in the soil-pipes or drains. Care must be taken to tightly close the door of the w.c., and the person putting the peppermint down must not emerge until the test has been finished. as he, of course, would taint the air in his vicinity, consequently two persons must be employed in applying the test. (Petroleum, terebene, oil of rosemary, ether, or other strong-smelling essential oil may also be used, but peppermint is considered the best for the purpose.)

This should be repeated in the lower w.c.'s, so as to test all the sinks, baths, yard gullies, and any other outlet for water connected with the drains. An outside gully may be similarly utilized for applying the test.

Smoke Test.—The *smoke test* should be applied by using one of the smoke testing machines used for this purpose. "The Eclipse smoke generator" is a very good one; the pipe can be introduced into the drain through the water seal of a trap.

The ventilators from soil and other pipes should not be closed until a constant discharge of smoke from their open ends is observed. When these openings are stopped the smoke in the pipes is subjected to pressure which assists in detecting flaws in the pipes and apparatus.

The smoke should either be forced into the drains through a gully outside of the house, or advantage taken of a ventilating opening so as to test the pipes and fittings for w.c.'s, baths, sinks, or other apparatus directly connected with the drains, and where the drains run under any portion of a building, the smoke should be forced up the drain towards the house. If any smoke is visible in the house, or any smell of the fumigating material can be detected, it indicates defects in the drains or pipes sufficient to admit sewer-gas into the house.

It is very necessary, when applying the smoke test, to make certain that the smoke actually passes into all branch pipes, and that it comes into close contact with the joints between the drain and every fitting. A convenient way of proving this is to withdraw the water from traps by means of a syringe; the smoke should then be freely emitted.

The outside drains should also be tested in section between the various traps and gullies; if they consist of old brick or stone drains, they probably leak, and are contaminating the earth.

The Eclipse Smoke Generator, as mentioned above, is shown in Fig. 498.

Messrs. Burns & Baillie claim that this is the only smoke generator, of any description whatsoever, which applies a positive test to drains.

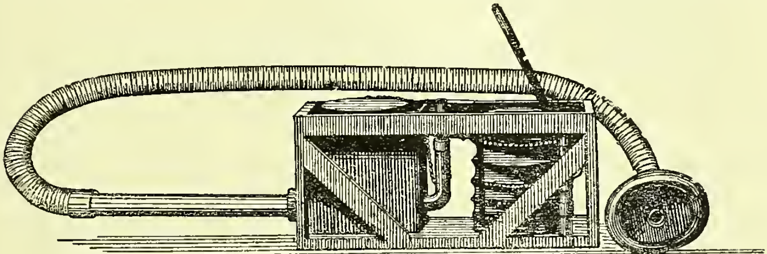


Fig. 498.—The Eclipse Smoke Generator.

It consists of a double-action bellows covered with specially prepared leather, and a copper cylinder, which, in applying the smoke test, is used as the fire-box. The cylinder is surrounded by a square copper tank, which is filled with water, so as to keep the fire-box as cool as possible.

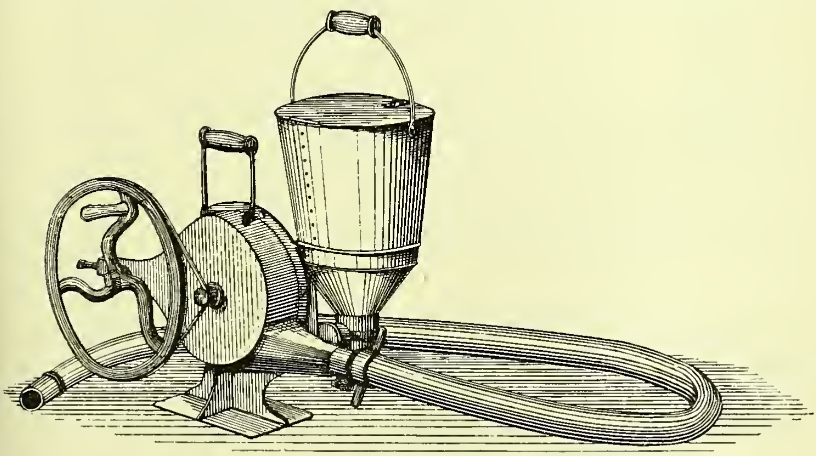


Fig. 499.—The Watts' Asphyxiator.

A deep copper cover or float is placed over the cylinder, and, with the water, forms an air-tight joint between them. An indiarubber tube of special composition, to withstand considerable heat, is connected to the outlet of the machine and the drain to be tested, both ends being made perfectly tight, and all openings, such as ventilation pipes, plugged.

The float rises, unless the drain leaks badly, with the action of the bellows, and indicates correctly the condition of the drain. If it is tight, the float remains stationary ; if it leaks, the float falls at a rate in proportion to the extent of the leak. The machine will, of course, prove the drain without smoke, but should a leak exist, smoke is applied to find it.

With all other contrivances for applying the smoke test to drains, if smoke is not perceived it is assumed that the drain is tight, but it is impossible with their use to prove that it is so.

The Watts' Asphyxiator.—The asphyxiator (Fig. 499) is also a very good smoke generator, and has been much used by the War Department.

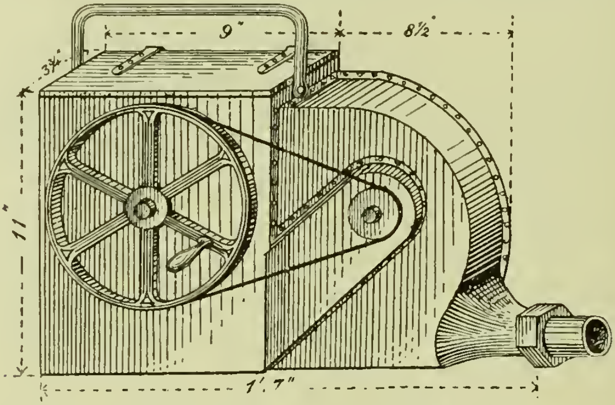


Fig. 500.—The Tyndale Asphyxiator.

It has fewer working parts, and is much more convenient for use than the eclipse smoke generator. The patentees and sole manufacturers are Messrs. John Watts & Co., Broad Weir Works, Bristol. The cost, inclusive of extras, is about £5.

The Tyndale Asphyxiator.—This machine (Fig. 500), whilst possessing the good qualities of the last-named apparatus, is much more compact and convenient for transport. There are no small parts liable to be lost. The patentee is Mr. W. C. Tyndale, Sanitary Engineer to the War Department, and is manufactured by Mr. O. D. Ward.

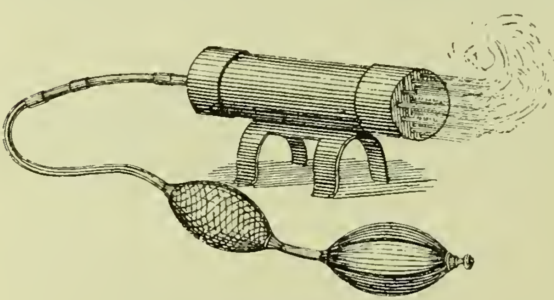


Fig. 501.—The Champion Fumigator.

The Champion Fumigator.—The " Champion " fumigator (Fig. 501) is on a smaller scale, and is consequently not so well adapted for large drains.

When testing short lengths of pipe it is convenient to use "smoke rockets," etc., as they are very portable.

Drain Grenades.—The "Banner" patent drain grenade, or drain ferret (Fig. 502), is very useful in connection with the scent test. It is made of thin glass, and is charged with very powerful pungent and volatile chemicals. When one of the "grenades" is dropped into a pipe, it breaks, and the effect produced by its contents is distributed only as intended, thus avoiding the mistakes which sometimes result from such tests, due to mismanagement or the careless handling of the necessary chemicals.

Fig. 502.—The Banner Drain Grenade.

Kemp's Patent Drain Tester.—This is a very useful invention, and is represented in Fig. 503. It is very easy of application : it is only necessary to remove the cover of the box and then secure the cover, lowering the "tester" into the w.c. pan or gully ; a pail of water, preferably hot, should be immediately thrown into the trap to wash the "tester" into the drain, where the contents will be at once discharged, producing a strong odour and a large volume of smoke in the drain. Defects can be readily detected by the pungent gas and smoke thus made finding its way through defective points, etc. The string with the spring and cap attached can be withdrawn from the trap, so as to prove that the contents has been satisfactorily discharged. Their cost is 1*s.* each, post free.

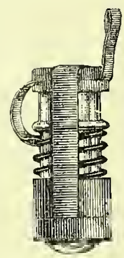


Fig. 503.—Kemp's Patent Drain Tester.

Pain's Smoke Cases or Rockets are intended to be placed in the drain. They are provided with a couple of thin strips of wood which when turned at right angles to the case extend on either side sufficiently to keep it off the invert of the pipe ; these rockets burn for a considerable time, and emit a dense volume of smoke with a pungent smell. They are supplied by James Pain & Sons.

Burnet's Patent Smoke Drain Tester.—The use of this test is exemplified in Fig. 504. The test is shown inserted in the trap, which should be done after flushing it with water ; the match is ignited, and the smoke case is passed through the water by means of the handle into the drain side of the trap. To find the outgo of the trap, a slight twisting movement of the handle is all that is necessary while inserting it. The tester should be left in the trap for about ten minutes before withdrawing it. By this means the drain is charged with a dense and pungent smoke, which will readily escape through any defect in the drain, thus showing plainly by sight and smell where it exists. The manufacturer is Mr. H. E. Burnet.

Analysis of Subsoil Water.—In some cases it may be desirable to analyse the subsoil water.

Old Culverts to be Destroyed.—Old culverts, if discovered, should be destroyed, as they harbour rats, and may prove to be sources of contagion.

Water Supply Pipes Disconnected from Sewer.—Direct communication between water mains and urinals, w.c.'s, or latrines should be cut off, special cisterns being provided for their supply, and the water in them should never be used either for cooking or drinking purposes, but reserved entirely for flushing the apparatus.

Fig. 504.—Burnet's Patent Smoke Drain Tester.

Underground Tanks.—The overflow from such tanks should invariably deliver on the surface, and never into an underground drain, manhole, or inspection pit, as trapping under such circumstances is sure to fail, and sewer-gas will be absorbed.

Examination of Drains.—The drains should be periodically examined from the manholes, and the clearing rods passed through them to ascertain that there is no obstruction.

Flushing.—The drains may be flushed separately, noting the speed at which the water travels, and whether or not accompanied by a deposit.

Water Mains Periodically Tested.—Water mains should be periodically tested, say once in six months, to ascertain that they do not leak, as leaky water mains may lead to in-suction of subsoil pollution, in addition to entailing a waste of water. Deacon's water meter is well adapted for this purpose, on account of its extreme sensitiveness.

Subsoil Drainage, etc.—Suitable subsoil drainage, by means of agricultural pipes, should always be provided, and in all cases care should be taken to ensure its remaining efficient as far as practicable, and free from contamination by sewage. All buildings should have a carefully constructed damp-proof course either of asphalte or pure Portland cement.

A layer of Portland cement concrete, from four to six inches thick, should be laid on the ground under all wooden floors to prevent damp from rising, and the growth of fungus.

Ample through ventilation should be provided under all floors.

When floors are re-laid, the space beneath should be disinfected.

Sites of Infectious Diseases to be Recorded.—A plan should be kept in each district showing, in selected colours, the location and date of each reported case of infectious disease.

Disinfectants.—The term "disinfectant," which is now in general use, is employed in several senses. By some it is applied to every agent that can remove impurity from the air; by others, to any substance which, besides acting as an air purifier, can also modify chemical action or restrain putrefaction in any substance, the effluvia from which may contaminate air; while by others again it is used to designate the substances which can prevent infectious disease from spreading by destroying their specific poisons.

Experiments have been conducted to determine the action of various disinfectants, in a greater or less state of concentration, upon definite microbes, and it has been found possible to define the degree of concentration necessary to constitute some of the chemical substances so employed as germicides. Many powerful deodorizers are not germicides, unless highly concentrated, although they may for a time render organisms inert by preventing their growth without actually destroying them.

The following list it is thought may be useful, and is, therefore, appended:—

Disinfectants, Powerful or Germicides.—Capable of destroying the most resistant microbes, under certain stated conditions of strength, temperature, and time.—Fire, boiling water, steam, hot dry air, perchloride of mercury, carbolic acid, izal, cressol, iodine, trichloride, osmic acid, permanganate of potash, iodine water, chlorine water, bromine water, formalin.

Disinfectants, Weak.—Capable of destroying microbes which are not in the state of spore.—The powerful disinfectants more diluted, chloride of lime, hydrochloric acid, sulphurous acid, salicylic acid, chromic acid, creosote, caustic lime, soda, and potash.

Antiseptics.—Capable of impeding or arresting the growth of microbes, but without necessarily destroying them.—Sulphate zinc, chloride lime, sulphate copper, sulphate iron, perchloride iron, boracic acid, borax, carbolic oil,* thymol,* oil of turpentine,* eucalyptus oil.

* Chiefly used as deodorants for concealing odours.

Deodorizer, but not an Antiseptic.—Permanganate of potash (Dibdin).

Aërial Deodorants.—For fumigation. Chlorine gas, sulphurous acid, nitrous fumes, ozone, euchlorine, formalin.

Powders for Disinfecting Purposes.—Manufactured and sold by the various makers whose names are given in the brackets. Izal powder (Newton, Chambers & Co.), sanitary powder (Jeyes), sanitas (Sanitas Co.), eucalyptol (Mackey, Mackey & Co.), chloride lime (Greenbank Alkaline Co.), surgical and tooth powder (Jeyes), carbolic acid (Mackey & Co.), pinewood and eucalyptus (Mackey & Co.), boro phenol (Calvert), kanphorkalk (A. Hornby).

Liquids for Disinfecting Purposes.—Manufactured and sold by the various makers whose names are given in the brackets. Izal (Newton, Chambers & Co.), phenol (Bobemf), perfect purifier and Jeyes' liquid (Jeyes), terebene (Cleaver), eucalyptol, camphorine, sulphenic acid, oxychlorogene, cresylic acid, carbolic acid (Mackey, Mackey & Co.), emulsion (Sanitas Co.), kresyline (Mackey), pixine (J. Wheeler).

Use of Disinfectants.—In any district where an epidemic prevails or is threatening, disinfection of all water-closets, etc., should be carried on systematically, either with solutions of chloralum, cupralum, carbolic acid, Burnett's fluid, or perchloride of mercury. Izal soap is very serviceable for scouring the floors of hospitals, sick rooms, etc.

Any manure heaps, or other accumulations of filth that might exist, which it is inexpedient to disturb or impossible to remove, should be covered with powdered vegetable charcoal to the depth of two or three inches, or with a layer of fresh dry earth, or with freshly-burnt lime, if charcoal cannot be obtained.

Cesspits and midden heaps may be disinfected with solutions of copperas (3 lbs. to the gallon of water), or with cupralum or chloralum (1 lb. to the gallon of water).

Cooper's salts might be used for the streets, lanes, and open courts. It need hardly be said, however, that in a town or district well looked after by the sanitary authorities no such filth accumulation as above mentioned would be allowed to take place at any time. [See *Handbook of Hygiene* (Wilson), page 385.]

Izal.—Izal, which is a comparatively new disinfectant, extracted from an unknown oil obtained from certain coke ovens, is a creamy looking emulsion, having an earthy smell, coupled with a faint odour suggestive of phenol. It is readily mixed with water, forming a milky emulsion. The following notice of izal appears in the *Theory and Practice of Hygiene*, by J. Lane Notter, M.A., M.D., and R. H. Firth, F.R.C.S. :—

Its disinfecting properties have been extensively investigated by us and found satisfactory. A 20 per cent. emulsion destroyed the highly resisting spores of *B. subtilis* and *B. mensentericus* in thirty-five minutes. A 10 per cent. emulsion killed virulent spores of anthrax bacilli in twenty minutes. Non-spore bearing specimens of the above bacilli were destroyed after five minutes' exposure to 0·5 per cent., or 1 in 200 emulsion. A 0·3 per cent. emulsion destroyed the streptococcus of pus; and exposure for half an hour to a 1 per cent. emulsion was sufficient to destroy the enteric fever bacillus and the spirilla of cholera.

Our observations dispose us to regard izal as a disinfectant of considerable practical value, and that for concrete cases of disinfection of morbid materials from the various infectious disorders, an exposure for fifteen minutes in the strength of 1 per cent. will be sufficient. Moreover, izal being free from poisonous properties, when introduced by injection into the tissues, or when administered by the stomach, possesses qualities which practically no other efficient disinfectant affords. The inhibitory or antiseptic value of izal is equally defined, as neither spores, micrococci, nor non-sporing bacilli and spirilla can germinate in medicated media, if the amount of disinfectant added is 0·1 per cent.

Izal is manufactured by Newton, Chambers & Co.

Formalin.—Formalin is the short term given by the Schering factory to a saturated 40 per cent. solution of formic aldehyde, the product of imperfect oxidation of alcohol. Formalin is supplied in various forms in a liquid state, and also in a dry form for gasification; the gas is harmless and antiseptic, it has great penetrating power. Dry formalin in any quantity is absolutely harmless to the human organism, but is convertible into active formalin gas by a very simple and easily managed contrivance in the shape of a lamp (the "Alformant," Fig. 505), patented by the Formalin Hygienic Co. in this country. This lamp had to be so constructed that when the stable body "paraform" was in the action of subliming, a sufficient quantity of water and carbonic acid should be led over the product of sublimation to convert it into active formic aldehyde, and this could be done by no other medium than the water of combustion supplied by a spirit flame. The whole of the paraform, by proper application, can thereby be converted into formalin gas, and the supply of gas is thus rendered simple and concise. Dr A. B. Griffiths states: "Paraform, or formalin in tablets, is a white solid, and is the polymer of formalin; it is a stable chemical compound not altered by heat, and only moderately antiseptic." This formalin gas obtained by means of the "Alformant" is far more effective as a germicide and a deodorizer

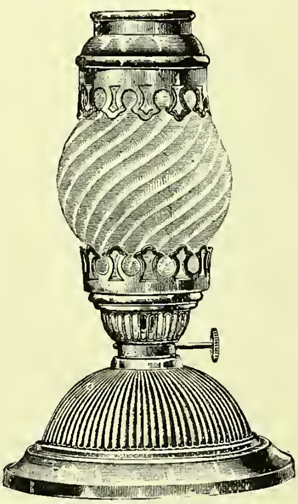


Fig. 505.—The "Alformant" Disinfecting Lamp.

than anything in the market. It may be stated that 1 gramme of paraform is equal to $2\frac{1}{2}$ grammes of liquid formalin, which is the saturated aqueous solution of 40 per cent. of gas. Formalin is supplied by the Formalin Hygienic Co., Limited.

Reevozone.—Charges of Reevozone for purifying the air in sewers are supplied by Reeves Chemical Sanitation, Limited. The method of application on an emergency is shown in Plate XXIXa. A very strong oxygenating vapour is evolved by the reaction of the chemicals, which deodorises and disinfects the sewer-air, and at the same time a strong disinfecting and deodorising solution is discharged into the sewer. The value of this system, from a public health point of view, lies in the fact that in the event of an epidemic occurring the whole of the sewer-air throughout the entire extent of any system of sewerage can be immediately purified ; and it is claimed, as the result of a practical trial, that if this were done the health officers would be in a position to almost instantly arrest the course of any zymotic outbreak occurring in their districts. The whole sewerage of a fair-sized town could be dealt with in a few hours. For further information about the Reeves system *vide* page 288, *ante*.

Condy's Fluid.—Condy's fluid, red and green, consists of a solution of potassium permanganate. It is essentially an oxidizing agent. It is odourless, and very useful for pouring down drains and w.c.'s. It arrests putrefaction for a short time, and prevents smell.

Chloride of Lime.—Chloride of lime is most powerful as a deodorant, and also as a sterilizer, especially at a high temperature.

Calvert's Carbolated Creosote.—Calvert's carbolated creosote is stated to be very effective for use in drains should any disease be known to be in the locality. The net cost per gallon for not less than forty gallons is 1*s.* 6*d.*, the cask being 6*d.* extra. About a quarter of a pint would be added to an ordinary bucketful of water. It is readily applied to the drains by supporting the cask over a small water tank connected by an overflow pipe and syphon with the drain.

Water can be turned on to the tank at any speed desired, and the proportional supply of carbolated creosote can similarly be regulated by a tap in the cask for drawing it off.

This plan has been adopted by Mr. C. Jones, C.E., Borough Engineer at Ealing.

Method of Application.—The method usually adopted for the application of disinfectants for purifying houses, rooms, etc., is to close all openings or apertures in a house or room, and employ the fumes of sulphurous acid, chlorine, nitrous acid, or other gases, with the object of destroying the germs of disease. But as these gases are truly aërial deodorants, the object in view is not always effected.

SKETCHES SHEWING METHOD OF APPLICATION OF "REEVOZONE" CHARGES FOR PURIFYING AIR IN SEWERS.

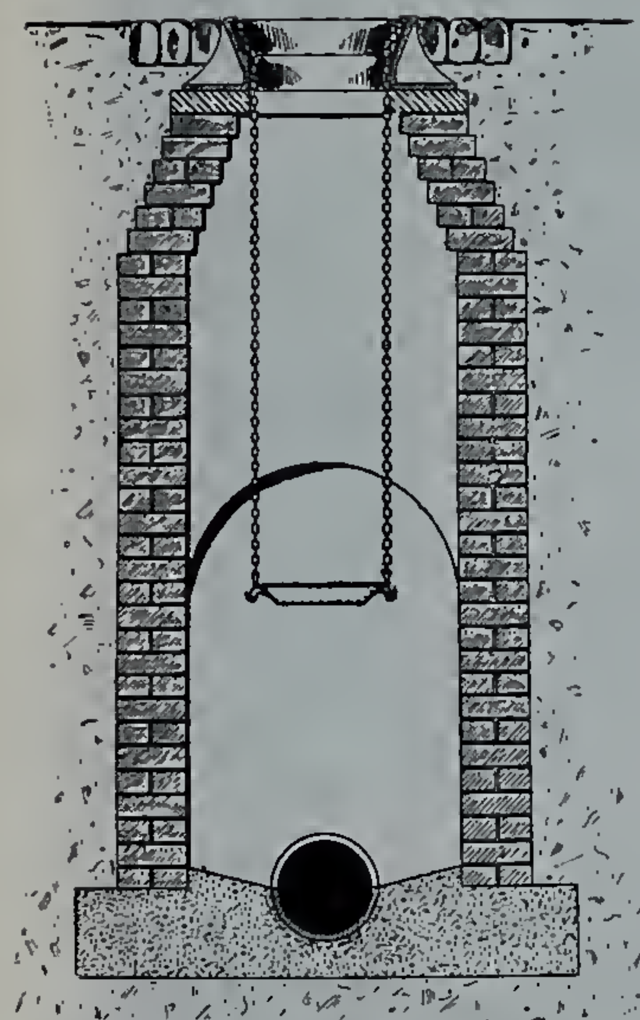


FIG. 1.—Tray charged with "Reevozone" let down into Manhole.

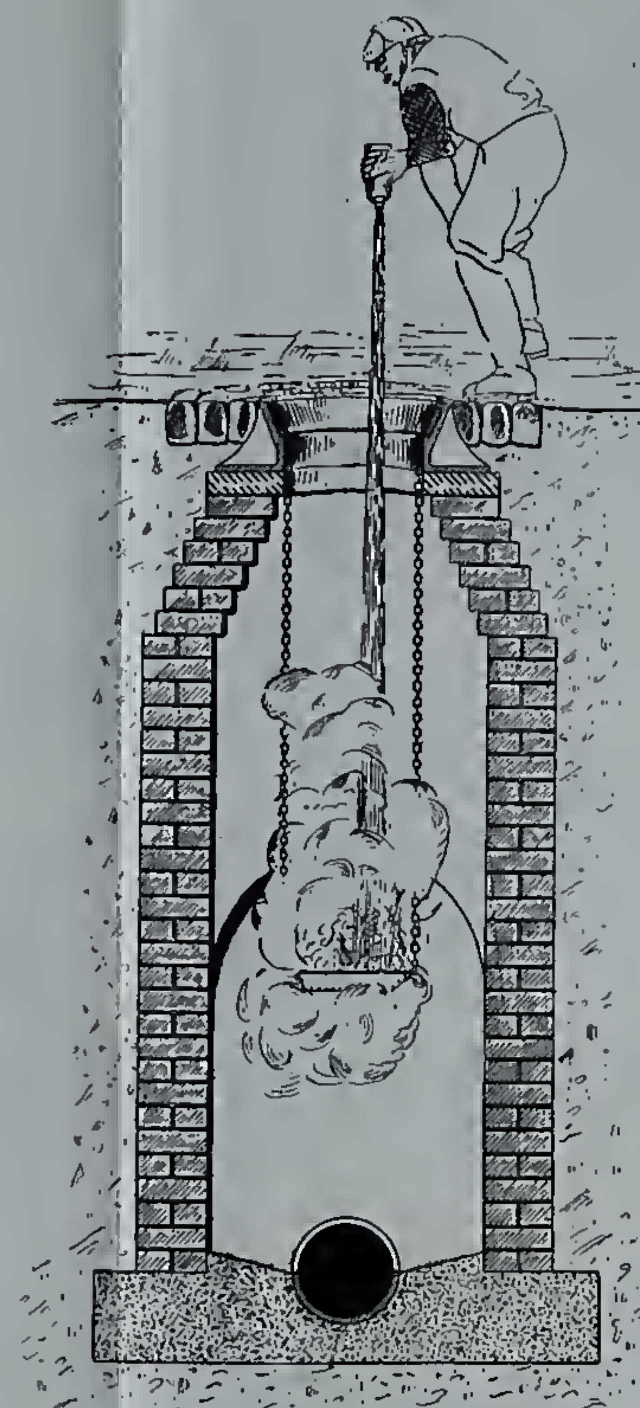


FIG. 2.—Distributing the Acids equally over the "Reevozone."

After applying the Acids (FIG. 2) cover with a sack for a few minutes to prevent fumes escaping.

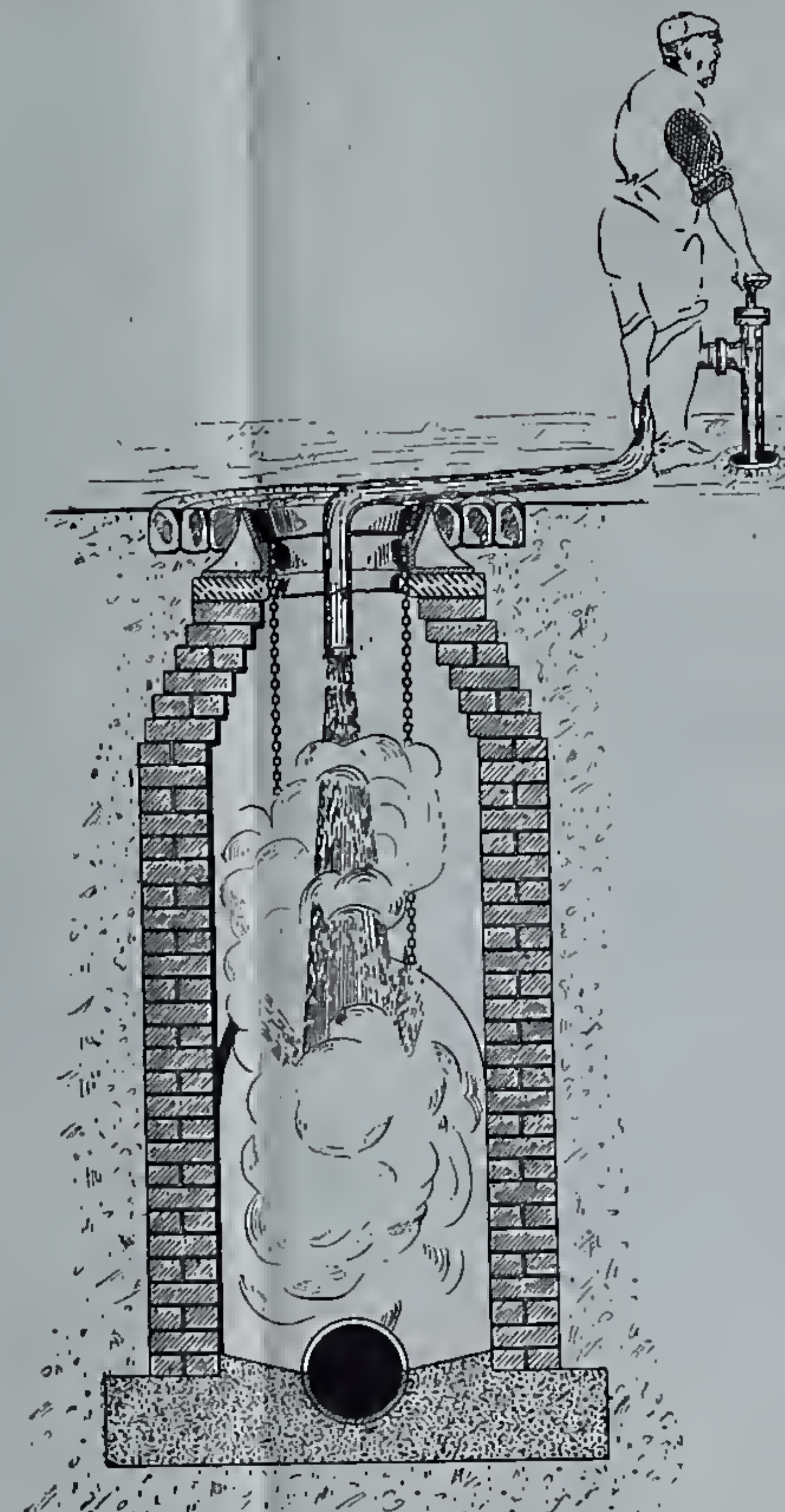


FIG. 3.—Mixing Chemicals and Flushing from Hydrant or Water-cart.

To face page 422.

It is, therefore, thought best to give an extract from the report of a process recommended by Drs. Dupré and Klein.

Extract from a Report by Drs. Dupré, F.R.S., and Klein, F.R.S., on the Best Method of Disinfecting the Room where Enteric Fever has occurred.

"Recent investigations have shown that gaseous substances, such as sulphurous acid gas and chlorine gas, which have been often used for the purpose of disinfecting rooms and similar localities, cannot be relied on, and that the only disinfectant that can be depended upon to kill micro-organisms, particularly those capable of producing the infectious diseases, is a free application of a solution of perchloride of mercury. It is well to have this solution slightly acid, coloured also in such a way that it shall not readily be confused with drinks or medicines, and proper caution should be given to prevent accidents in its use.

"The solution is made by dissolving half an ounce of corrosive sublimate and one fluid ounce of hydrochloric acid in three gallons of common water, with five grains of commercial aniline blue, or ordinary violet ink, to give the fluid a conspicuously distinguishing character. Proper caution should be given to avoid accidents, as the solution is a deadly poison.

"The solution is easily made, keeps well, is very inexpensive, and should not be further diluted, and is easily applied. The use of non-metallic vessels (wooden or earthenware house tubs or buckets) should be enjoined on those who use it.

"The method of applying the disinfectant will, no doubt, vary under different conditions, but the following may be taken as an outline of the procedure that should be usually adopted:—

"The walls should be thoroughly stripped of all paper or other covering and scraped. All skirting should be removed. The floor boards should be taken up, and all rubbish and dust found in the space under the joists should be removed, care being taken that the scrapings, rubbish and dust are not thrown away, but are burnt, as they may contain infectious germs.

"After a thorough clearance has been made, as described above, the whole of the ceilings, walls, joists, architraves and window linings, and any other fixed woodwork in the rooms, together with the spaces below the floors, should be carefully washed with the solution of perchloride, prepared as above directed. The solution should be applied with a whitewasher's brush.

"A syringe should be used to squirt the solution into any nooks or interstices which the whitewasher's brush will not properly reach.

Whenever used, the solution should be liberally applied, and should be allowed to remain overnight.

"Any dilapidated flooring or woodwork should be burnt, and only the thoroughly sound portions should be re-fixed, and these, before being fixed, should be thoroughly washed with the solution, allowed to remain over night, and afterwards washed with warm water, in order to remove the mercury.

"Ceilings and walls should be limewashed, and all fixed woodwork should also be washed with warm water, in order to remove the mercury." (See *Report on the Sanitary Condition of the Richmond Barracks, Dublin*, by Mr. Rogers Field, C.E.)

In executing the above recommendations, the workmen should be provided with special clothing, *e.g.*, white duck to fit over their ordinary apparel, respirators, goggles and gloves, and, further, they should be made to wash their faces before leaving work, at meal-time, etc.

Sanitary Maxims.*

1. It is the duty of every householder to ascertain for himself whether his own house be free or not from well-known dangers to health.

2. This duty, imperative at all times, is of surpassing urgency in a house where a confinement is expected, or a surgical operation to be performed.

3. As a rule, the soundness of the sanitary arrangements of a house is taken for granted, and never questioned until "drain-begotten" illness has broken out. In other words, we employ illness and death as our drain detectives.

4. Whenever gas from sewers, or the emanations from a leaking drain, a cesspool, or a fouled well, make their way into a house, the inmates are in imminent danger of an outbreak of typhoid fever, diphtheria, or other febrile ailment, classed together under the term "zymotic," not to speak of minor illness and depressed vitality, the connection of which with sewer-gas is now fully established. Sewer-gas enters a house most rapidly at night when the outer doors and windows are shut, and is then perhaps most potent in contaminating the meat, the milk, and the drinking water, and in poisoning the inmates.

5. The more complete and air-tight the public sewers of a town, the greater the danger to every house connected with such sewers, if the internal drain-pipes of the house be unsound and not *disconnected*. In houses so badly connected, sewer-air is "laid on" as certainly for the detriment of health as coal gas for illumination ; and you can turn off coal gas at the meter.

* By T. Pridgin Teale, M.A., as published by the National Health Society, Berners Street, London.

6. Every hotel throughout the kingdom and in our watering places, every house let as lodgings, ought to have its sanitary arrangements periodically inspected and duly licensed.

7. A house in which children and servants are often ailing with sore throat, headache, or diarrhœa, is probably wrong in its drainage.

8. Scamped drain work is one of the most dangerous of the sanitary flaws of new buildings; it is also one of the most common and one of the most difficult to detect, and is rarely found out except by means of the illness it produces.

9. If you are about to buy or to rent a house, be it new or be it old, *take care, before you complete your bargain,* to ascertain the soundness of its sanitary arrangements with no less care and anxiety than you would exercise in testing the soundness of a horse before you purchase it.

10. If you are building a house, or if you can achieve it in an old one, let no drain be under any part of your house, *disconnect* all waste pipes and overflow pipes from the drains, and place the soil pipe of the w.c. *outside* the house and ventilate it.

11. If there is a smell of drains in your house, or a damp place in a wall near which a waste pipe or a soil-pipe runs, or a damp place in the cellar or kitchen floor near a drain or a tank, let no time be lost in laying bare the pipes or drains until the cause be detected.

12. If a rat appears through the floor of your kitchen or cellar, and a strong current of air blows from the rathole when chimneys are acting and the windows and doors of the house are shut, feel sure that something is wrong with a drain.

13. If you are tenants and your landlord refuses to remedy the evil, do it at your own cost rather than allow your family to be ill.

14. Many a man who would be aghast at the idea of putting small quantities of arsenic into every sack of flour, and so by degrees killing himself and family, does not hesitate to allow sewer-gas to poison the inmates of his house, even in the face of the strongest remonstrances of his medical adviser.

15. A landlord may reasonably look for interest on money which he spends for the benefit of his tenant; but he is committing little short of manslaughter if, by refusing to rectify sanitary defects in his property, *he saves his own pocket at the expense of the health and lives of his tenants.*

16. If you be a landlord, do not intimidate your tenants or threaten to give them notice to quit if they complain of defective drainage or sewer-gas in the house.

CHAPTER XIV.

SEWAGE DISPOSAL.

Efficient Removal Necessary.—It has already been pointed out that it is most essential to health to provide for the efficient removal of all decomposing refuse, as well as the foul water, from houses and factories as soon as possible, before putrefaction sets in ; the question of its final disposal then becomes a matter of the greatest importance.

At one time, when communities were small, the final disposal of their sewage was accompanied with but little difficulty ; the sea or the nearest river was the natural receiver into which it was poured without hesitation, and without any apparent harm or injury to other communities situated lower down the stream. In the former case, no evil results followed, and in the latter also the action of the stream on it is of such a nature as to purify the sewage to a great extent by processes which are now daily becoming better understood ; the quantity, however, must not be too great.

The increasing size and number of villages and towns along the river banks have, however, in many instances, become so great as to gradually poison the water supply to the towns below, so that towns like Manchester, Liverpool, and Birmingham, for this and other causes, have been obliged to go to enormous expense to bring water for their use from the lakes in Westmoreland and Wales, where the collecting areas can be kept free from contamination. The present supply for London is taken from the upper atwersheds of the Thames, from the river Lea, New River, the Kent Co., etc. ; but at one time it was not considered satisfactory, and it was proposed to emulate the above towns in a gigantic water scheme. The whole of the London supply of potable water is now passed into subsiding and storage reservoirs before being filtered, beds of sand and gravel of various depths are used for the purpose, and on careful analysis in 1894 Mr. Dibdin found that the filtered river-water supplied to London is practically as good as the unfiltered Welsh waters. It would be more beneficial to soften the London water by Clarke's process, and the adoption of the system, according to the same authority, would improve it in respect of its "chemical quality and number of bacteria to a degree comparable with that of the Welsh sources." The object of the appointment of the Rivers Pollution Commissioners is to prevent rivers from being fouled by the discharge of crude sewage into them, and to oblige the various communities to adopt some method for its purification before such discharge.

All manufacturers should be compelled to treat their trade refuse water before discharging it into the sewers, so that it will not require more oxidation than the ordinary sewage of the district.

Standard of Purity.—The standard of purity suggested by the Rivers Pollution Commissioners is that the effluent on discharge into a river, etc., should not contain more than 0·3 parts by weight of organic nitrogen in solution in 100,000 parts by weight of effluent.

Systems.—The following are the systems which have so far been tried and adopted in many instances :—

I. The dry earth.
II. Discharge into the sea or tidal estuary.
III. Irrigation.
IV. Filtration.
V. Precipitation.
VI. Electrolysis.
VII. Bacteriolysis.

I. **Dry Earth.**—In Eastern countries, for the most part, the natural method of using dry earth obtains. The excrement is collected at once and buried daily. The foul water finds its way along open channels to a pit provided for the purpose, and being attacked by the oxygen in the air, and also well dusted, loses its injurious qualities as far as any emanations from it are concerned. Channels of this description are readily cleansed. The pits are also emptied daily, and the liquid buried with the excrement.

In more humid climates there is a difficulty in applying dry earth, at any rate on a large scale, as the earth would have to be dried.

Ashes are sometimes used in place of dry earth, but are not so satisfactory.

II. **The Sea, or Tidal Estuary.**—Many engineers of high standing maintain that where practicable the sea, or the tidal estuary of a river, is the right place for the discharge of sewage, as no costly works are then necessary. This system involves the direct discharge of the sewage at ebb tide, so as to carry out the sewage to a good distance from the shore, and diffuse it into the sea before the tide begins to flow. Great care is, however, essential to secure this result. Float observations should be made not only of the surface tides and currents, but also of those at different depths, and the effect on the sewage, in consequence of the difference between its specific gravity and that of salt water, carefully considered. The rise and fall of the tides, and the configuration of the coast line, must also be studied as bearing on the question.

Where tidal currents exist, the point of discharge should be situated below the place, in the direction of the falling tide, and not above it.

The greatest difficulty with such outfalls is at neap tides, and consequently it is the effect of these tides on the discharge that should be considered. As, however, the flow of sewage in sewers towards the outfall is continuous, it is usual to form storage tanks or reservoirs in which the sewage is accumulated during the rise of the tide, and from which it is discharged at the beginning of the ebb.

This system is only available in a limited number of places (*e.g.*, towns near the sea coast), and cannot be efficiently employed for the disposal of sewage of inland towns at such distances from the outfall that the sewage would take longer than six hours in reaching the point of discharge.

Sewage discharged into land-locked harbours and deep bays soon becomes a nuisance, as is evidenced by many seaside towns.

Sea water delays the oxidation of organic matters, so that the foul constituents of crude sewage, which in river water would be liberated and got rid of in time, are preserved in sea water, and if washed up on the foreshore, they accumulate and form dangerous deposits ready for the quickening action of the summer sun, when gases injurious to health are evolved.

In tidal estuaries the sewage seldom travels a sufficient distance out to sea and away from the shore, owing to the currents and rise of tides; the sewage is frequently carried back and deposited above the outfall. The evil effects of discharging sewage into a tidal river were fully exemplified in the case of the London sewage, between 1848 and 1855. The cesspits formerly in general use in London were abolished by the Act of 1848, and the culverts and drains, hitherto intended for surface water only, were brought into use for sewage. These drains were totally unsuited to the purpose, discharging their contents at the low-water level, and during the period of low-water only. The sewage carried down by the one tide was brought back by the next, the progress towards the sea being very slow; thus the accumulation in the river daily became more intense and offensive, and the banks covered with mud which at low-water gave off very foul exhalations. In order to remedy this state of things, large drainage works were executed, with the object of discharging the sewage lower down the river, at Barking Creek and at Crossness on the south side of the river, about twelve miles below London Bridge. These works were completed in 1864 to 1865. A total of about two hundred million gallons of sewage is discharged as an average daily from these outfalls. For some years no ill effects were noticeable, but at length the old condition of things reasserted itself, and in 1884 Mr. Dibdin recommended the precipitation of the suspended matters prior to the discharge of the effluent. This was carried out in 1890-2 with marked success. The effluent is only discharged between high-water and half-ebb.

Some types of sewer outfalls are given in Plates V. and VI., page 16. Careful ventilation is requisite in order to prevent the sewer-gas from being forced up the drain by the pressure of the rising tide.

In Plate XI., page 22, is given a plan of Rangoon showing the sewage and compressed air mains, ejector stations, air compressing stations, etc., by which the sewage of this town is discharged into the river, and carried out to sea.

A description of the Sewage Disposal Works at Southampton is given on pages 570—583, *post*.

III. **Irrigation.**—Another system is that of irrigation, which consists in passing the sewage over land, in order to use its fertilizing properties, and at the same time to purify it before running the liquid into a river or other watercourse.

Loamy porous soil is the best for sewage irrigation from a sanitary point of view.

Unless the subsoil is sand or gravel, it is usual with the denser top soils to provide some subsoil drainage, increasing it in amount and depth with the density of the soil to be utilized, so as to give a free exit for the water, and prevent the ground from getting water-logged.

Where the land is of a stiff clayey nature, there are considerable difficulties in adapting it for irrigation. In undrained clay land, under ordinary circumstances, cracks one and two inches wide and five feet deep are sometimes met with, and it has been found that these are intensified in drained land, with the result that direct passage of sewage and surface water into them has occurred on sewage farms of this nature, so that the effluent is not purified as intended. It is thus very unsuitable for irrigation, unless the surface is specially prepared, as mentioned under the head of broad irrigation, and other treatment should be resorted to.

Different soils vary very considerably in their power to decompose sewage by utilizing the ammonia (the principal fertilizing agent) and other constituents which are capable of nourishing vegetable life, as well as at the same time effecting its purification.

The progressive stages of our knowledge of the manner in which land acts in purifying sewage is marked by the following extracts :—

Researches of Dr. Voeckler.—According to the *Researches of Dr. Voeckler*, an eminent chemist, as quoted from the *Journal of the Royal Agricultural Society*, No. 28, page 544 :—

"1. All soils experimented upon had the power of absorbing ammonia from its solution in water.

"2. Ammonia is never completely removed from its solution, however weak it may be. On passing a solution of ammonia, whether weak or strong, through any kind of soil, a certain quantity of ammonia invariably passes through. No soil has the power of fixing completely the ammonia with which it is brought into contact.

"3. The absolute quantity of ammonia which is absorbed by a soil is larger when a stronger solution of ammonia is passed through it; but relatively weaker solutions are more thoroughly exhausted than stronger ones.

"4. A soil which has absorbed as much ammonia as it will from a weak solution, takes up a fresh quantity of ammonia when it is brought into contact with a stronger solution.

"5. In passing solutions of salts of ammonia through soils, the ammonia alone is absorbed, and the acids pass through generally in combination with lime, or when lime is deficient in the soil, in combination with magnesia or other mineral bases.

"6. Soils absorb more ammonia from stronger than from weaker solutions of sulphate of ammonia as of other ammonia salts.

"7. In no instance is the ammonia absorbed by soils from solutions of free ammonia, or from salts of ammonia, so completely or permanently fixed as to prevent water from washing out appreciable quantities of ammonia.

"8. The proportion of ammonia which is removed in the several washings is small in proportion to that retained by the soil.

"9. The power of soils to absorb ammonia from solutions of free or combined ammonia is thus greater than the power of water to re-dissolve it."

Thoroughly drained land has the property of converting the nitrogenous organic matters in the sewage into nitrates, but only those which are absorbed rapidly by vegetation are utilized, the remainder are carried through the ground, so that an excess of sewage cannot be taken up by the crops; notwithstanding this, the land may act well as a purifier for sanitary purposes.

It is necessary to give the soil sufficient time to get thoroughly aërated — from four to eight days — as otherwise nitrification often ceases altogether, and even percolation is stopped by the soil getting clogged.

Aëration is effected by atmospheric air following the last part of each dose of sewage as it sinks through the filtering material, and so oxidizes the organic matter retained in its pores.

If under these circumstances the quantity of sewage is not in excess of the power of the soil to deal with, it does not appear, even when unaided by vegetation, to lose its power or become saturated.

Mr. Warrington's Researches.—Mr. R. Warrington examined the question of the action of soil on sewage, and in 1884 presented a paper on the subject to the British Association for the Advancement of Science; the following is an extract:—

"**The Theory of Nitrification.**—Till the commencement of 1877 it was generally supposed that the formation of nitrates from ammonia, or nitrogenous organic matters, in soils and waters was the result of simple oxidation by the atmosphere. In the case of soil, it was imagined that the action of the atmosphere was intensified by the condensation of oxygen in the pores of the soil; in the case of waters, no such assumption was possible. This theory was most unsatisfactory, as neither the solutions of pure ammonia nor any of its salts could be nitrified in the laboratory by simple exposure to air. The assumed condensation of oxygen in the pores of the soil also proved to be a fiction as soon as it was put by Schlœsing to the test of experiment.

"Early in 1877, two French chemists, MM. Schlœsing and Müntz, published preliminary experiments, showing that nitrification in sewage and in soils is the result of the action of an organized ferment, which occurs abundantly in soils and in most impure waters. The evidence for the ferment theory of nitrification is now very complete. Nitrification in soils and waters is found to be strictly limited to the range of temperature within which the vital activity of living ferments is confined. Thus nitrification proceeds with extreme slowness near the freezing point, and increases in activity with a rise of temperature till 37° C. (99° Fahr.) is reached; the action then diminishes, and ceases altogether at 55° C. (131° Fahr.). Nitrification is also dependent upon the presence of plant food suitable for organisms of low character. Recent experiments at Rothampstead show that in the absence of phosphates no nitrification will occur. Further proof of the ferment theory is afforded by the fact that antiseptics are fatal to nitrification. In the presence of a small quantity of chloroform, carbon bisulphide, salicylic acid, and apparently also phenol, nitrification entirely ceases. The action of heat is also equally confirmatory. Raising sewage to the boiling point entirely prevents it undergoing nitrification. The heating of soil to the same temperature effectually destroys its nitrifying power. Finally, nitrification can be started in boiled sewage, or in other sterilized liquid of suitable composition, by the addition of a few particles of fresh surface soil, or a few drops of a solution which has already nitrified, though without such addition these liquids may be freely exposed to filtered air without nitrification taking place.

"The nitrifying organism has been submitted as yet to but little microscopical study ; it is apparently a micrococcus. . . .

[This suggestion has since been confirmed.]

"**The Distribution of the Nitrifying Organism in the Soil.**—Small quantities of soil were taken, at depths varying from two inches to eight feet, from the freshly-cut surfaces on the sides of pits sunk in the clay soil at Rothampstead. The soil removed was at once transferred to a sterilized solution of diluted urine, which was afterwards examined from time to time to ascertain if nitrification took place. From the results it would appear that in a clay soil the nitrifying organism is confined to about 18 inches of the top soil ; it is most abundant in the first six inches. It is quite possible, however, that in the channels caused by worms or by the roots of plants, the organism may occur at greater depths. In a sandy soil we should expect to find the organism at a lower level than in clay, but of this we have as yet no direct evidence."

The result of more recent research is that the nitrifying organisms have actually been discovered to exist in sandy soils, and to be in active operation at greater depths, even as much as from three to four feet below the surface.

Nitrification in soil is due to the action of at least two separate microbes. The first converts ammonia into nitrous acid, and the second transforms the nitrous acid into nitric acid.

Professor Henry Robinson, in his book "Sewerage and Sewage Disposal," published in 1896, says "that the changes that have to take place in sewage to effect purification, or that are necessary to enable the manurial ingredients in it to be best adapted to the requirements of plant life, are due to the nitrifying action of micro-organisms. It is essential that the conditions should be adhered to which favour the cultivation of these bacteria. Where the land under treatment is open and pervious, the most solid part of the sewage, as well as the dissolved and finely-suspended organic matters, admit of being liquefied in the interstices of the soil, and of being converted into the harmless nitrates and nitrites which are so beneficial to plant life. Where the land is impervious, this can only be partially effected, and in such cases the liquefaction of the solids by bacteriological influences has to be brought about by chemical treatment, so that the fluid that is applied to the land is both free from that which would clog the pores, and is at the same time highly charged with the nitrates and nitrites which are available for vegetation. If they are not required by the crops, they are in a form that can pass away without causing pollution or nuisance."

The absence of phosphates injuriously affects nitrification, and the addition of lime has been found advantageous to plant life where large quantities of sewage have to be disposed of by irrigation.

It is apparent from the foregoing that the presence in sewage of refuse from chemical works in consequence of its sterilizing power may form a great hindrance to its purification by the soil.

Settling Tanks.—Before applying the sewage to land, it should be allowed to settle, so as to get rid of the heavier portions, as well as the silt, grit, etc., derived from the streets and roads. To effect this, settling tanks have been adopted.

Settling tanks are constructed on two principles: that of "quiescence" or "absolute rest," and "continuous"; the latter is found to answer best, provided the sewage is not less than two hours in passing through the tank. These tanks should be cleaned out once in three days. The odour from them is very unpleasant, and to obviate this a suitable deodorant or disinfectant should be used.

General Form of.—In this country settling tanks have generally been made rectangular in plan, the proportion of width to length being 1 to 4. The bottom has a fall of 1 in 80 towards the inlet end, but lately

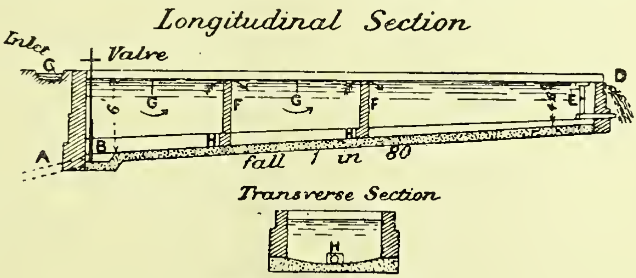


Fig. 506.—Settling Tank.

considerable variations in shape and design have been introduced, some of which are described later on. The maximum flow per hour of sewage from a town has been estimated at 8 per cent. of the daily flow, and to admit of the above rate of flow through the tanks, they should be capable of holding 16 per cent. of the total amount of sewage to be dealt with.

This again should be multiplied by three, bringing the total capacity to be provided up to nearly 50 per cent., and should be divided amongst three sets of tanks. One would stand empty whilst being cleaned out, and the two others would provide for the sewage and excessive fluctuations in the rainfall. A number of small tanks is much more convenient than a few large ones.

In Fig. 506 sewage enters at C, passes under the scum-boards G, and over the cross valves F; the liquid overflows at D, or is carried off by the floating arm E. The sludge collects at the bottom and is transferred from the upper compartments by the sludge doors H, until it is eventually drawn off by the valve B, through the pipe at A.

It is best to work the tanks on the intermittent system, if a clear effluent is required, as the solids are precipitated more readily during a period of rest. The continuous system is, however, more generally employed, as it involves far less tank accommodation.

Dundrum Tanks.—Three settling tanks are used by Mr. Kaye Parry in his system of sewage disposal. Each tank contains 5,000 gallons of sewage, and is seven feet square and sixteen feet deep. The sewage is admitted to each in succession near the bottom, and as it rises to the surface the finer particles are left behind.

The Dortmund Settling Tank (Plate XXX.).—A circular settling tank has been tried at Dortmund, in Germany, by Mr. Carl Kinebühler. The sewage is passed through the ordinary pattern settling tank in the first instance, and is thus freed from floating impurities, lime and sulphate of alumina being added successively. The sewage then passes down a vertical zinc pipe to a depth of about thirty feet, through the axis of a cylindrical tank; the pipe is provided with radial arms, to distribute the sewage evenly over the area, and below them the tank is cone-shaped. The sludge settles at the bottom, and is gradually pumped out as it consolidates by a six-inch suction pipe, led down inside the supply pipe to near the bottom of the tank. The effluent is drawn off by troughs, so arranged as to subdivide the surface equally, and thus avoid setting up a current. The flow is kept at a uniform rate of about fifteen feet per hour.*

Broad Irrigation consists in passing the sewage over large tracts of land with the object of purifying it. The difficulty in this case very often is to find sufficient land conveniently situated for the purpose, the allowance being one acre per one hundred of population.

Almost any soil is suitable for irrigation if well and properly drained. When the surface of the land is relied on for the purification of the sewage, it should present a gentle slope, in order that the sewage may travel slowly forwards in a lateral direction, and thus admit of the surface being regularly wetted throughout, and of the liquid draining off readily, so that the surface may dry after the application of the sewage. Not only does the top soil require levelling to effect this, but the surface of the subsoil should be similarly disposed parallel to it, the top soil being carefully removed for this purpose, and afterwards replaced.

Broad irrigation was practically carried out at the sewage farm at Wimbledon, where the soil is clay. The ground was divided into plots of about four acres, by means of roads twelve feet in width; under the centre of each road a drain was laid to a depth of six feet.

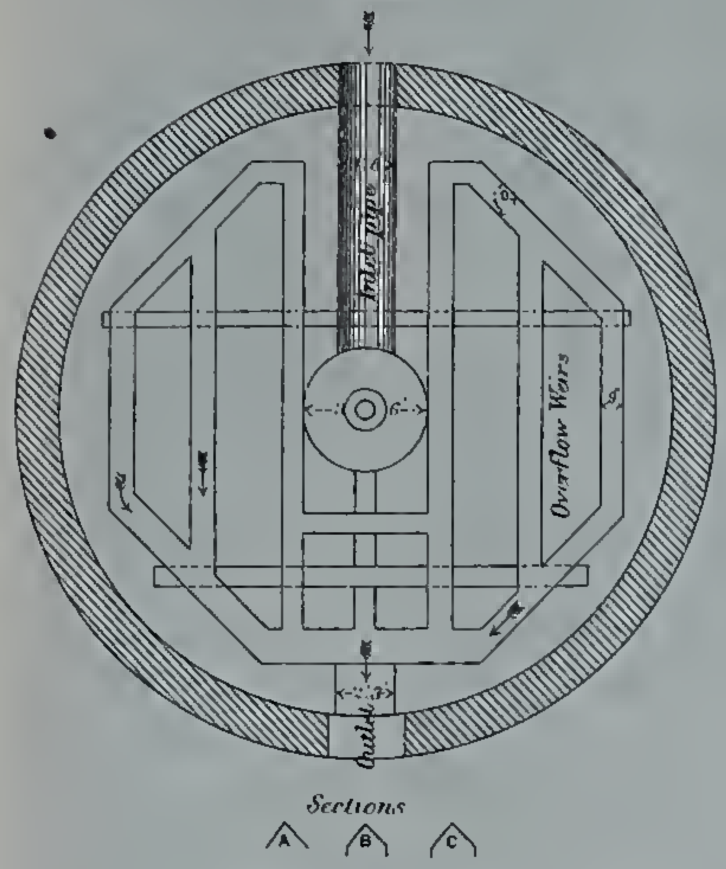
The surface was very carefully levelled to avoid ponding, and was ploughed up to a depth of nine inches, being afterwards covered with

* Mr. W. Santo Crimp says in a letter to me, dated July 12th, 1898, "the Dortmund tanks have not proved to be as satisfactory in working as we were led to suppose; the sides become coated with filth, which decomposes, making the effluent very unsatisfactory."

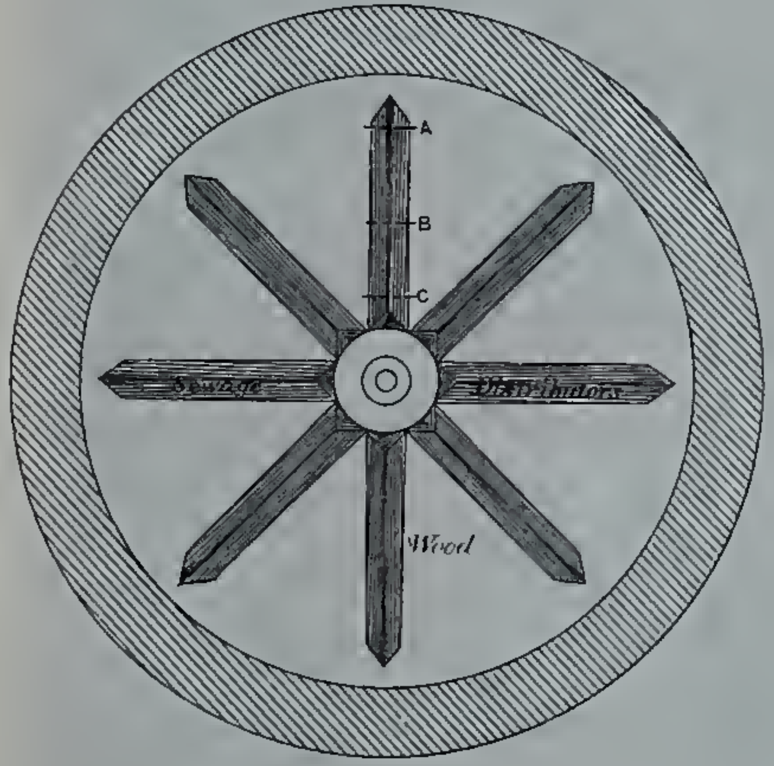
PLATE XXX.

DORTMUND SEWAGE TANK.

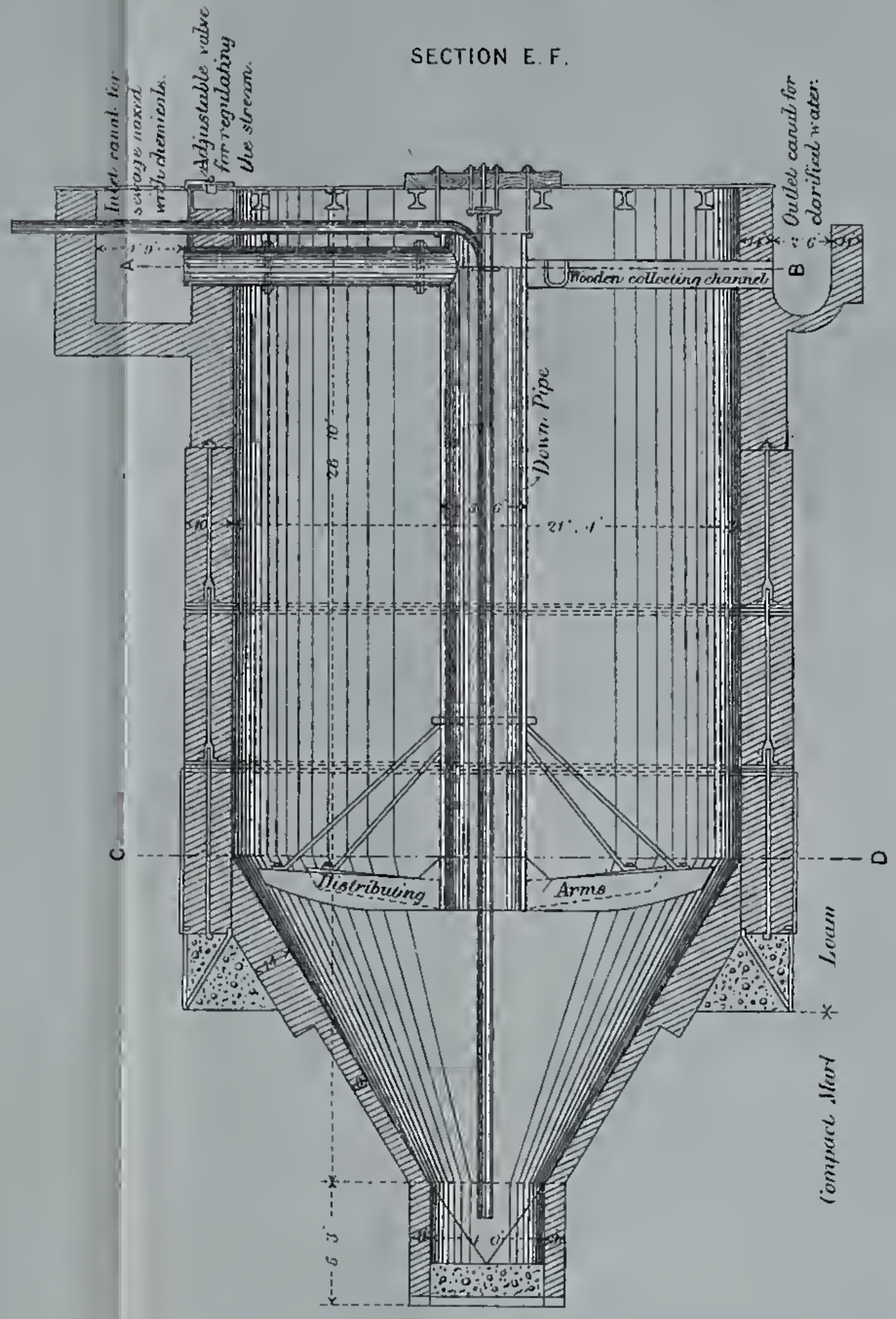
SECTION A.B.



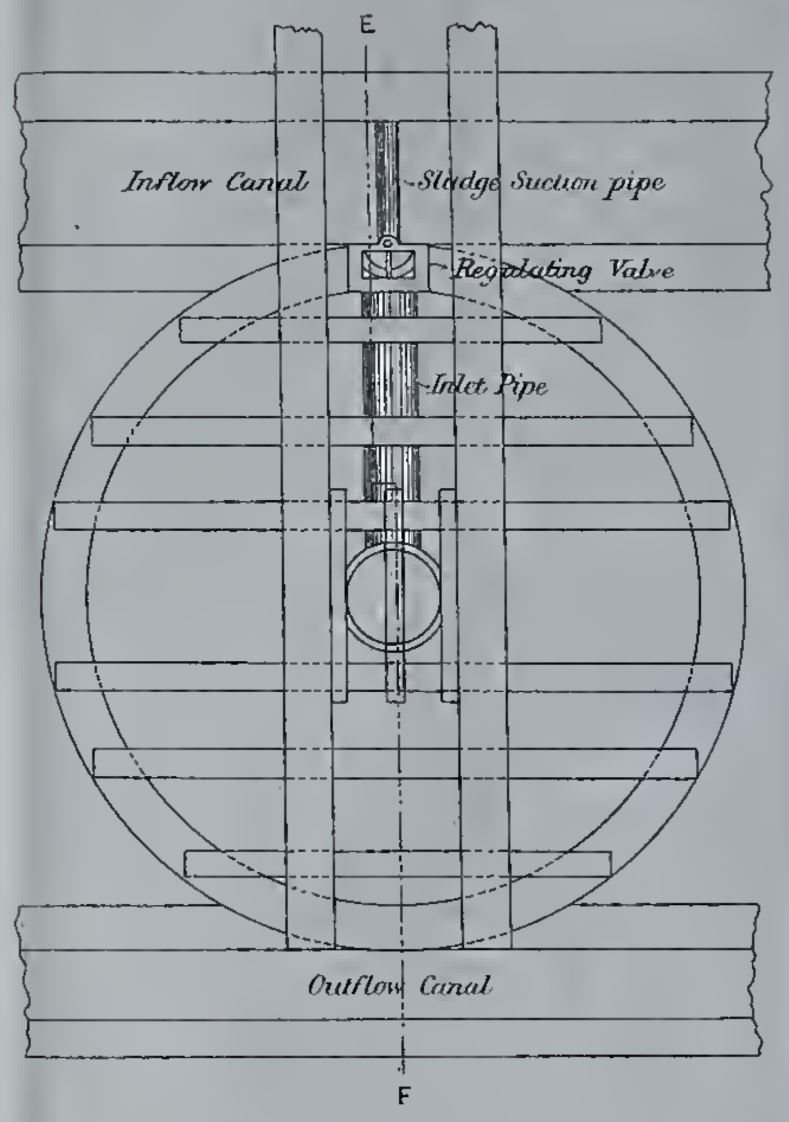
SECTION C.D.



SECTION E.F.



PLAN OF TOP.



JAMES AKERMAN, LITH, 6 QUEEN SQUARE, LONDON, W.C.

three inches of screened town ashes. The result was that a porous surface about one foot in thickness was obtained, through which the sewage could pass in a lateral direction. The ground was cropped and ploughed every other year, so that porosity was maintained. The sewage was applied intermittently, and was not allowed to exceed 20,000 gallons per acre per diem.

Beddington Irrigation Farm.—Plate XXXI., page 436, is a plan of *Beddington Irrigation Farm*, borough of Croydon, Surrey. It consists of 525 acres, of which 420 acres are laid down for broad irrigation. The remaining 105 are occupied by 4 farmsteads, 14 cottages, the manager's house, etc. The subsoil consists of gravel, very open in some places, and sand.

The soil varies from loam to a light, free, open soil, but it is all very suitable for irrigation.

The aspect of the farm is a gentle slope from east to west, averaging about 1 in 175.

The sewage flows on to the farm by gravitation through two outlets.

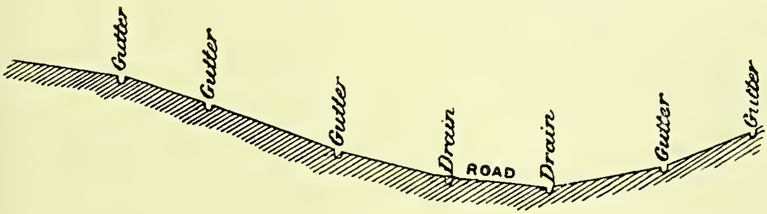


Fig. 507.—Catchwater System.

There are no storm overflows, and the whole of the storm water is delivered on the farm.

The effluent water passes into the river Wandle.

The cost of the works, under-drainage, effluent outfalls to the river Wandle, farm buildings, cottages, etc., was £18,000.

The working expenses are said to be covered by the sale of produce.

The population of the districts draining on to this farm is about 80,000, and water-closets are in general use.

Distribution over Land.—The distribution of the sewage over the land is effected in various ways, three of which are illustrated. Fig. 507 is the "*catchwater*" method, and is only suitable for steep ground; the gutters are laid along the contours to receive the surplus liquid from the upper slopes, and distribute it again by overflow to those below.

Ridge and Furrow System.—Fig. 508 shows the "*ridge and furrow*" *system,* for use on flat and heavy soil; it consists of a series of shallow ridges with gentle slopes falling between them, and channels or "carriers" following the ridge-lines. The ridges should be about half a chain apart, and a longitudinal fall given to the furrows.

The Preparation of the Land for irrigation should be as simple and cheap as possible; the main carriers, or channels, may be constructed substantially in concrete, brick laid in cement, or stoneware, as in Fig. 509 ; but the tributary ones, as a rule, are made by hand, or by the

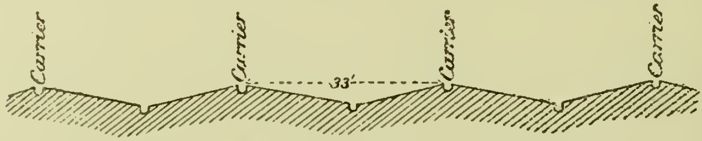


Fig. 508.—Ridge and Furrow System.

plough, though occasionally, in exceptional cases, carriers of the form given in Fig. 510 are of advantage.

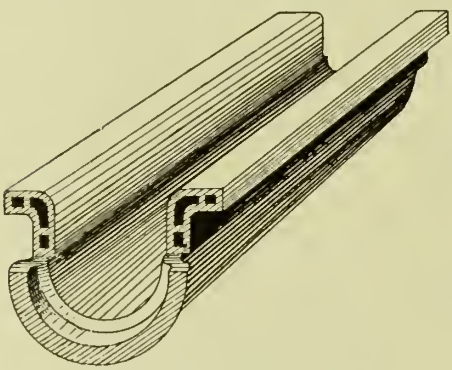


Fig. 509.—Doulton's Stoneware Channel or Carrier.

Main carriers are generally from one to two feet wide, and about six to ten inches deep, and should have a fall of about 1 in 500 or 600, and the distributing carriers of about 1 in 300.

Sluice-valves may be of wood in stoneware chambers (as above), or as made by Doulton & Co.—of metal. "Stops" of metal or wood can also be placed, wherever needed, in the surface carriers by farm labourers, to divert the flow from those parts of the land that require it.

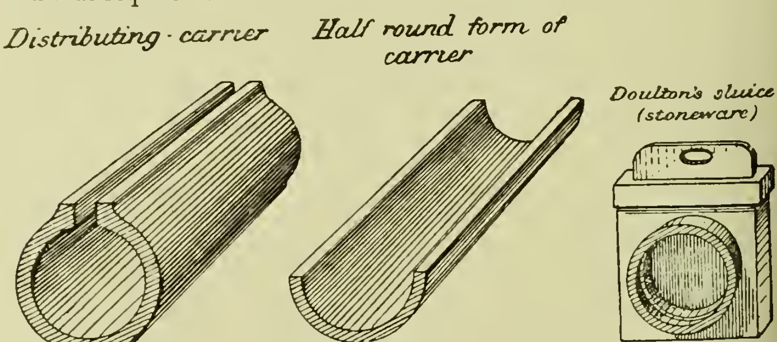


Fig. 510.

Acreage.—The acreage employed varies considerably, from one acre to 55 inhabitants, as at Leamington, to one acre to 208 at Blackburn; the number of gallons per head per diem being 38.

PLATE XXXI.

CORPORATION OF CROYDON.
PLAN OF
BEDDINGTON IRRIGATION FARM.

J Akerman, Lith 6, Queen Square, London W.C

An acre is covered one inch deep by 100 tons of sewage.

Crops Suitable.—The best crops are all kinds of market garden produce, mangold-wurzel, beetroot, cabbages, carrots, wheat, oats, and barley. Grazing can also be carried on, as the sewage does not affect the milk.

If the volume of sewage to be disposed of is too large to admit of the cultivation of cereals, then the crops must be limited to rye-grass, mangold-wurzel, etc. The sewage may also be passed through land thickly planted with the American water-weed, anacharis, duckweed, sedges, flowering rush, common reed, etc., or through beds of osiers or alder trees.

Capacity of Land.—An acre of such land is said to purify more than 3,000,000 gallons per diem.

In climates where the average temperature is high, and the rainfall is small in comparison with the amount of evaporation from the ground, or where the rainfall is intermittent with periods of drought, irrigation is the most efficacious for the disposal of sewage. In humid climates, where the average temperature is less than 50° Fahr., and evaporation is not great, the land becomes quickly saturated with the large quantity of liquid passed daily on to it, and thus favourable results are not realized from the employment of this system.

When the question of the disposal of the sewage by irrigation was taken in hand in England some years ago, great profits were anticipated from its utilization; and although sewage is said to have a value of from ½*d.* to 2*d.* a ton, or 10*d.* per head of population per annum, yet the results of all the experiments of the last twenty-five years tend to show that it has practically no commercial value, so that irrigation cannot be made a profitable undertaking, although in some instances sewage farms manage to pay their way.

IV. **Filtration (Intermittent Downward).**—Another method of irrigation, known as intermittent downward filtration, is sometimes employed.

Mr. Bailey-Denton defines intermittent filtration as "the concentration of sewage at *regulated intervals* on as few acres of land as will absorb and cleanse it, without preventing the production of vegetation."

He states that the sewage of 1,000 persons can be applied to an acre of such soils as are most suitably constituted, and of 250 to those badly constituted.

Heavy clay soils are not adapted to this purpose.

When land is to be used as a filter, the surface should be laid out in level beds, and the sewage applied to each bed then passes vertically downward through the pervious stratum, from which, in a more or less purified condition, it escapes by means of subsoil drains, or an existing porous subsoil of sand or gravel, into a stream or watercourse.

When the filtration areas are very porous, and the sewage is applied in small volumes by gravitation from grounds not provided with storage tanks, the distribution would be made by ridge and furrow, as recommended by Mr. Bailey-Denton (*vide* Fig. 511), so as to ensure uniformity of application.

Constant Aëration Required.—Land thus used as a sewage filter requires constant aëration by being dug or ploughed over.

Plate XXXII. is a plan of land laid out for intermittent downward filtration at Hitchin, Hertfordshire.

The quantity of land in this farm is 22 acres, of which 19 acres are devoted to filtration (Plots I., II., and III.), and surface, or broad rrigation (Plots IV. and V.).

The subsoil is peat of a boggy nature, mixed with gravelly clunch (lower chalk).

The sewage is distributed through the filtration areas by means of furrows, the positions of which are altered every winter or early spring,

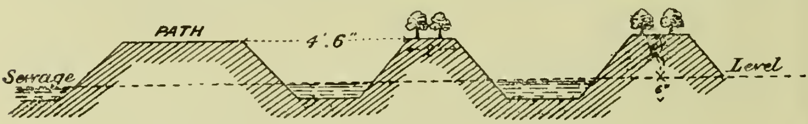


FIG. 511.—Ridge and Furrow System, for intermittent filtration.

care being taken that they are not placed directly over the under-drains. By the use of these furrows (Fig. 511) the liquid is not allowed to come in contact with the leaves of the growing vegetation, but spreading laterally reaches the roots, and can thus be applied at any stage of growth without disadvantage.

This farm was laid out from plans, etc., of Mr. Bailey-Denton, at a cost of £2,300.

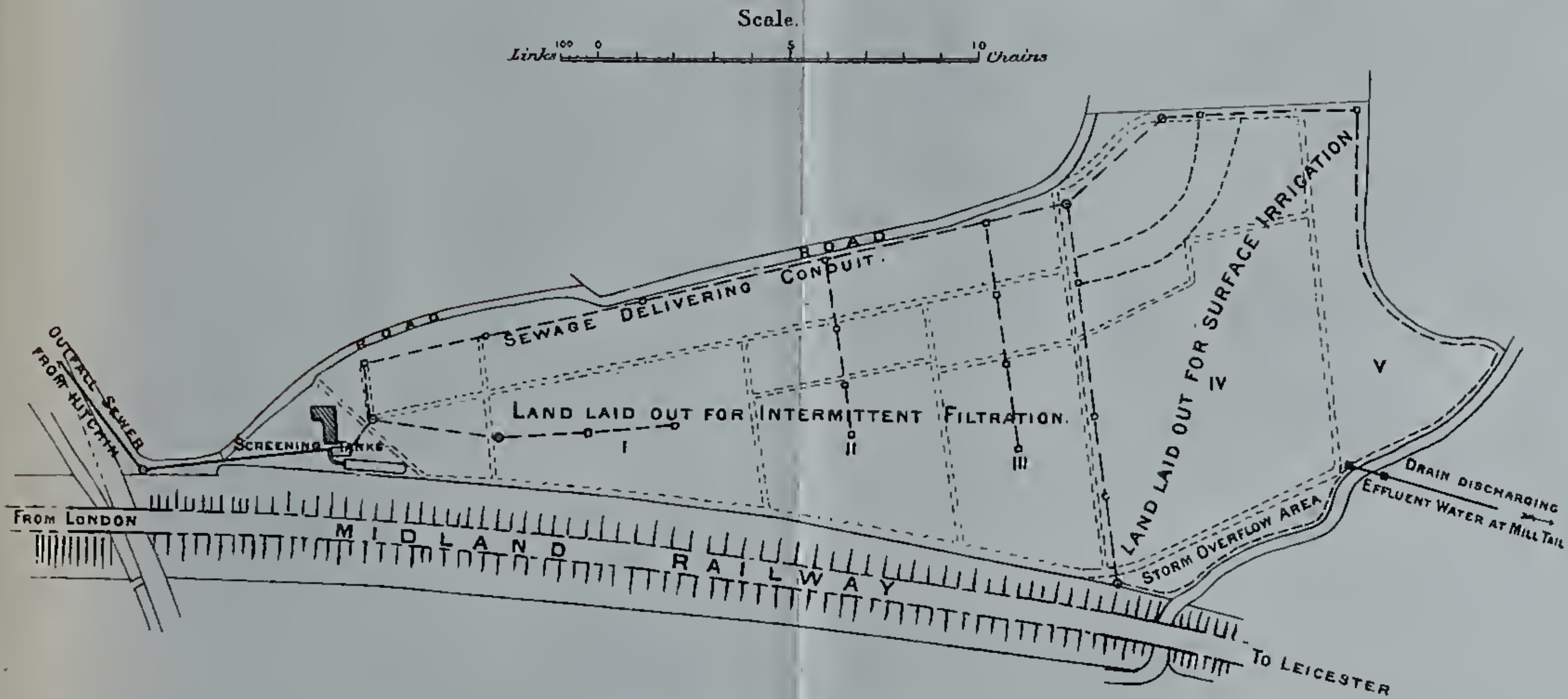
The population is about 10,000, and water-closets are in general use.

Considerable discredit has been cast of late years on sewage farms, but this, in the opinion of Mr. Bailey-Denton (1896), is owing to neglect in the efficient maintenance of the farms "by the local authorities responsible for their success after the engineer who designed them has completed his duties." The sewage should invariably be passed in its crude state through a simple filter composed of gravel, coke, broken ballast, or some other suitable material, before being applied to the land ; if this is done, the best results may be anticipated. Mr. Bailey-Denton, in his book "Sewage Purification brought up to Date, 1896," gives a description of a great many sewage farms throughout Great Britain in which the system has been found to give very satis-

PLATE XXXII.

HITCHIN, HERTS.

LAND UTILIZED FOR SEWAGE CLEANSING.



The delivering sewage conduits are shown thus - - - - - - - -

The distributing chambers " " " - - - -o- - -

factory results, not only with regard to the disposal of the sewage, but also as to the character of the effluent. "Care should always be taken to deliver for surface irrigation only such quantities of sewage as are required by the cultivator, by taking advantage of the power we always possess of cleansing any quantity of sewage by intermittent filtration through a small area of land."

Filters.—By this system the sewage is clarified by removing all organic or inorganic matters suspended in it by mechanical means. It has been supposed that the liquid in passing through the pores of the filter beds carries a quantity of atmospheric air with it, which tends to oxidize the animal and vegetable matters, and prevent them from becoming injurious. Some of the organic compounds are also decomposed. Filters are generally formed of beds of sand, gravel, burnt clay, coke, charcoal, moor-earth (sand and peat), sawdust, pumice, coal, polarite, etc., and other hard vegetable substances exposing considerable surface.

It is evidently possible, from the evidence already given, to construct filter beds superior in oxidizing power to that possessed by any ordinary soil and subsoil, *e.g.*, the porous substratum required might be formed of a system of subsoil drain-pipes, and over these a few feet of soil might be placed. The soil selected should be of a porous nature, and contain a considerable proportion of carbonate of lime and organic matter; it should be taken from the upper six inches of a good field.

Sewage contains the organisms necessary for its own destruction, and under favourable conditions these may be so cultivated as to effect the purpose. A filtering medium of pure sand and limestone, treated intermittently with sewage, will, after a time, display considerable purifying powers, the surface becoming covered with oxidizing organisms derived from the sewage.

Where the amount of manufacturer's refuse is largely in excess of the excrementitious matter, in consequence of the foul water containing acids and metals in solution, it is preferable to adopt filtration in place of irrigation, as the liquid would destroy the crops. Filtration may also be applied after precipitation, when extreme purity of effluent is required before delivery into a river.

Massachusetts, Experimental Investigations by the State Board of Health of.—The following are extracts from the report of the State Board of Health on the filtration of sewage, giving the general view of the results of their investigations (p. 577):—

"We have now filtered sewage intermittently through clean gravel stones larger than robins' eggs, through filters made of various grades of gravel and of sand, to a sand whose particles average but 0·004 inch in diameter—a fine granular dust—as well as through soils and through peat.

"With the gravels and sands, from the coarsest to the finest, we find that purification by nitrification takes place in all, when the quantity of sewage is adapted to their ability, and the surface is not allowed to become clogged by organic matter to the exclusion of air.

"With fine soils containing, in addition to their sand grains, two or three per cent. of alumina and oxide of iron and manganese, and six or seven per cent. of organic matter, we find that, when only six inches in depth, resting upon fine sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and dry away to allow air to enter the filter is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability, such a filter may give an excellent effluent, quite free from bacteria.

"With greater depth of soil the quantity that can be filtered will evidently become less ; and, with the depth of five feet of such soil, we have found nitrification did not take place ; and, although it was probable that no bacteria came through, the organic matter in the effluent was at the end of two years nearly as great as the sewage. This soil remained continually so nearly saturated that when only 5,000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce any nitrification ; and the chemical result with this material was, throughout the two years of its trial, nearly the same as would be expected if the filtration had been made continuous, instead of intermittent.

"With peat upon the surface of a filtration area, even to the depth of only one foot, its imperviousness to liquid, and the quantity that it will retain until it evaporates, renders intermittent filtration impracticable ; and a sand area thus covered with peat can be rendered efficient for filtration only by the removal of the peat from the surface.

"The experiments with gravel stones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months ninety-seven per cent. of the organic nitrogenous matter, a large part of which was in solution, as well as ninety-nine per cent. of the bacteria, which were of course in suspension, and enabled these organic matters to be oxidized or burned, so that there remained in the effluent but three per cent. of the decomposable organic matter of the sewage, the remainder being converted into harmless mineral matter.

"The mechanical separation of any part of the sewage by straining through sand is but an incident which, under some conditions, favourably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.

"With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year, and the conditions just mentioned appear to be most favourable for their efficient action, and at the same time most destructive to them and to all kinds of bacteria that are in the sewage.

"The coarse sand filtered 117,000 gallons per acre per day for three months, after which the quantity was increased, and averaged for five months 177,000 gallons per acre per day. The purification was less complete for the first month after the change, but in the second and third months it was more complete than with the quantity given above. The fourth and fifth months, however, give less satisfactory results, showing that the filter was becoming overburdened; the surface became much clogged with organic matter, and the sum of ammonias of the effluent increased to 2·7 per cent. of those of the sewage; but the bacteria in the effluent decreased to 0·1 of one per cent. of the number in the sewage. This filter was evidently doing more than it could continue to do indefinitely. The other filters, filtering quantities decreasing with their perviousness from 60,000 gallons per acre per day to 9,000 gallons, indicated that they would continue giving as good results indefinitely. In all cases, except that of No. 1, they gave an effluent containing about one-half of one per cent. of the nitrogenous organic matter of the sewage, as shown by the sum of the ammonias; and from 0·08 to 0·001 of one per cent. of the number of bacteria in the sewage. It is probable that the three less pervious materials allowed no bacteria to be brought down from the sewage, but that the numbers of one or two or three in 100,000 of the number in the sewage grew in the underdrains.

"The essential difference between intermittent filtration and continuous filtration of sewage is, that in the former air is allowed to enter the filter during the intermissions, and in the latter air is excluded from the filter.

"If from any cause the surface becomes impervious to air, by the material becoming so retentive of water that no air can enter between the applications of sewage, the result is similar to that when filtration is continuous; no nitrification takes place, and the effluent gradually grows to contain as much organic matter as the sewage."

V. **Precipitation.**—The method of precipitation is more properly called the chemical treatment of sewage; it means the formation of solid compounds by introducing chemical substances into the sewage. The solids so formed, in settling, drag down with them the suspended matters held in solution in the sewage, together with a small proportion of the polluting matters; the proportion, of course, varies with the amount of solid matters deposited. The effluent from the tanks then flows at once into a river or stream, or may be required to be passed over land, or be filtered through it. It may be drawn off from the surface by floating outlets, as in Fig. 512, which represents an improved

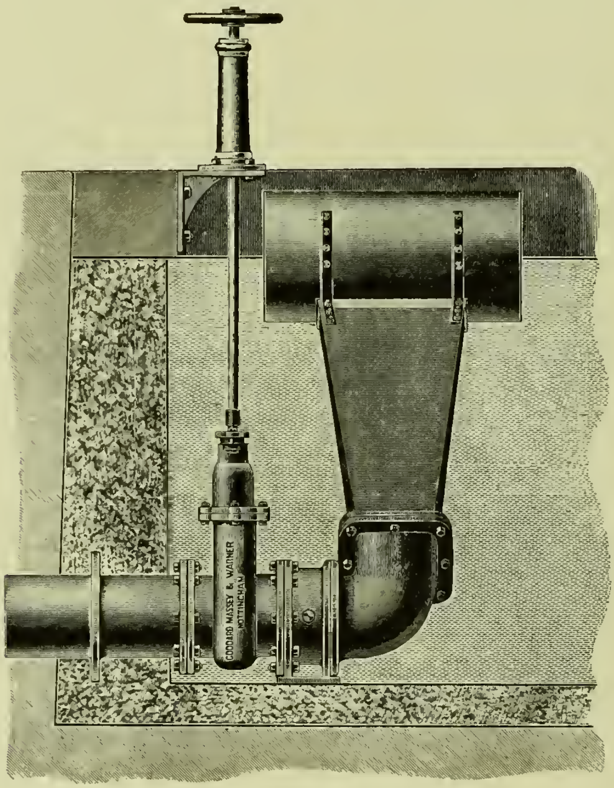


FIG. 512.—Floating Arm, with Sluice Valves.

floating arm, by Messrs. Goddard, Massey & Warner. These arms work automatically and without risk of clogging or stoppage caused by the flow of sewage. They may be arranged with sluice valves to work either inside or outside the precipitation tanks, and are made in sizes from six to fifteen inches in diameter.

Keirby's Patent Mixer is shown in Fig. 513. It is intended for supplying material to sewage in lump or powder. It is claimed that this machine will dissolve and distribute with absolute certainty and regularity any of the well-known precipitants (in lump or in powder), and automatically vary the strengths of the precipitants in solution according to the increase and decrease in the flow of sewage.

The mixer has a perforated cage or cylinder containing the precipitant, and is surrounded by an outer cylinder sufficiently large for clearance and is mounted upon a shaft in the frame of the outer cylinder ; and near the bottom of the outer cylinder is secured a pipe, connected to a water supply, required to dissolve the precipitant, and at another part of

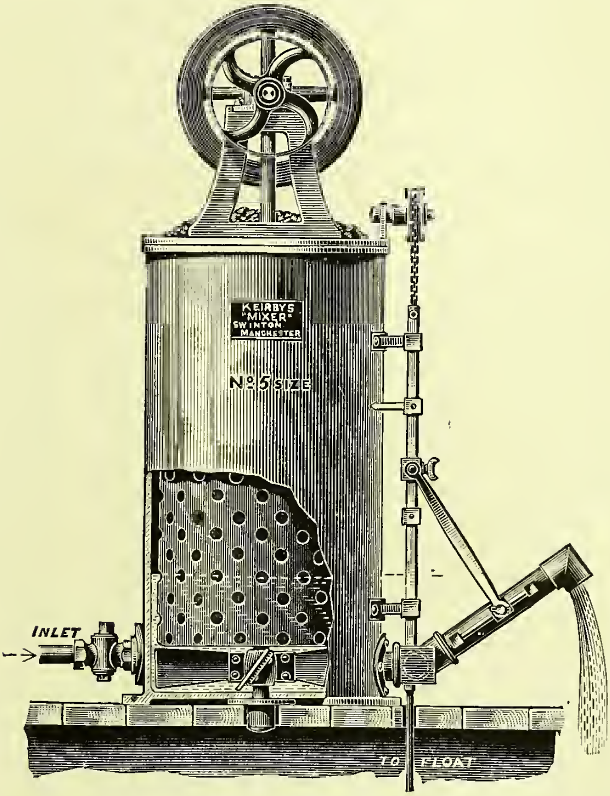


Fig. 513.—Keirby's Patent Sewage Mixer.

the outer cylinder, at about the same level, is an outlet to which is coupled a swivel joint and pipe, or hollow arm, through which the solution from the cylinder is discharged. This arm is capable of being raised or lowered by a connection to a float in the culvert, drain, sump, or other convenient place into which the sewage is admitted or through which it flows. The inner cage is so arranged that it can be rotated, and by its rotation the water is agitated and produces rapid absorption.

It will be understood that as the flow of sewage increases the float will raise the outlet arm, and thereby raise the liquid to a greater height in the cylinders, and so absorb more of the precipitant, and consequently a stronger solution will be discharged, and *vice versâ*, as the flow of sewage decreases and the outlet arm falls, the level of the liquid in the cylinders will be lower, and less of the precipitant will be dissolved.

An adjustable slide is secured to the movable arm, which affords a means of regulating the number of grains of the precipitant to each gallon of sewage under treatment.

Only a very small quantity of water (sewage water or otherwise) is required to be constantly running through the mixer. The quantity does not require varying; it is the strength of the solution that is varied and not the volume.

It is made in a great many sizes. No. 5 Mixer, 30in. × 60in., is stated to be suitable for a flow of 1,000,000 gallons per twenty-four hours. It requires rather less than half horse-power to drive it at a speed of about fifty revolutions per minute. The water inlet pipe is 1¼in. in diameter.

There are a great variety of these machines, such as that made by Mr. John Wolstenholme, Messrs. Goddard, Massey & Warner, and other makers.

Precipitating Agents.—The conditions for a good precipitating agent are as follows:—

1. It should be cheap and abundant.
2. It should cause rapid subsidence of the precipitate formed.
3. It should be neither actively nor cumulatively poisonous.
4. It should not have a tendency to render any portion of the suspended matters soluble.
5. It should not have any distinct colour, nor generate one with the substances it may encounter.
6. It should ensure the production of a precipitate of minimum bulk with maximum defecation.
7. The resultant effluent should not be alkaline.
8. The precipitate or sludge should part with moisture readily.

It may be further noted that sewage is more easily precipitated when warm than when cold, and also when the precipitating agent is added to it *hot*.

According to Mr. Dibdin, it is very necessary before adopting any system of precipitation to consider the question of the possible solvent action of the reagent on the suspended matters contained in particular sewage to be treated. An excessive use of chemicals for precipitating purposes is to be avoided, as it is not only a waste to use more than is absolutely necessary, but the action of the precipitant is actually reduced by such excess.

Variety of Processes.—A vast number of processes have been tried, of which the following are the principal.

Lime Process.—The lime process consists in the addition of lime in a perfectly caustic state, in the proportion of twelve grains per gallon, after a preliminary straining of the sewage.

The lime is first of all well slaked with water, and ground in a mortar mill, or lime mixer, so as to be in a finely divided or creamy condition ; it is then necessary to thoroughly incorporate it with the sewage, and agitate it well before allowing the mixture to settle. It should afterwards be allowed to rest quietly for one hour at least, but where the amount of sewage to be dealt with is large, this is not practicable, and the continuous system has to be adopted. The precipitate should be consolidated and deprived of its water as soon as possible, as putrefaction soon sets in and creates a nuisance.

The purest lime should be used, such as that obtainable from the upper chalk and the crystalline limestones of Derbyshire and other counties.

The addition to the above of $\frac{1}{3}$ grain of chloride of lime per gallon of sewage is supposed to have beneficial results, especially in hot weather, in preventing the growth of fungus.

The cost of this process has been found to be about eightpence per head of population per annum. This precipitant, however, renders the effluent alkaline, and its discharge into rivers favours decomposition, and is very destructive to fish.

The lime process is employed at Birmingham, Burnley, and Wolverhampton.

The Amines Process.—In this process the precipitants employed are herring-brine and lime in the proportion of four grains of the former and twenty-two and a half of the latter per gallon. The process was tried at Salford in 1891, on the continuous flow system ; the effluent was odourless and clear, and the wet sludge produced amounted to about twenty-six tons per 1,000,000 gallons.

Lime and Sulphate of Iron.—For some years lime and sulphate of iron have been used as precipitating agents in connection with the disposal of the Metropolitan sewage at Barking and Crossness. The proportion employed is about four grains of lime and one of sulphate of iron to a gallon of sewage. The object is to separate the solid matters in suspension from those in solution, the latter being scarcely at all affected by the process, though a certain percentage of them is also removed where the conditions are favourable, but no reliance can be placed on such a result as a rule.

The amount of lime used must be strictly limited, as it has the effect of rendering a portion of the suspended matters soluble, and thus damaging the character of the effluent.

Special mixers are used for mixing and adding the lime and the iron to the sewage, as well as precipitating tanks.

The precipitating tanks at Barking and Crossness are on the continuous flow principle, so that the amount of deposits is not so great as it otherwise might be. The composition of the crude sewage as received, according to Mr. Dibdin,* varies very much with the time of year, as all storm water is included, the average number of grains of suspended matter per gallon being from 29·1 to 38·1, and in the effluent after precipitation from 5·0 to 8·9.

The effluent as discharged into the Thames is not appreciably different from the river water, and the matters still remaining in solution in the sewage effluent are those most readily oxidised by the action of the river. If further purification of the effluent were required, it might readily be effected by the use of bacterial agency.

Lime and Alumina.—The Glasgow Sewage Works deal with the sewage of the eastern district of the city of Glasgow, and were opened on the 2nd May, 1894. Lime and alumina are the precipitants employed. The following is a description of the works (Plate XXXIII.):—

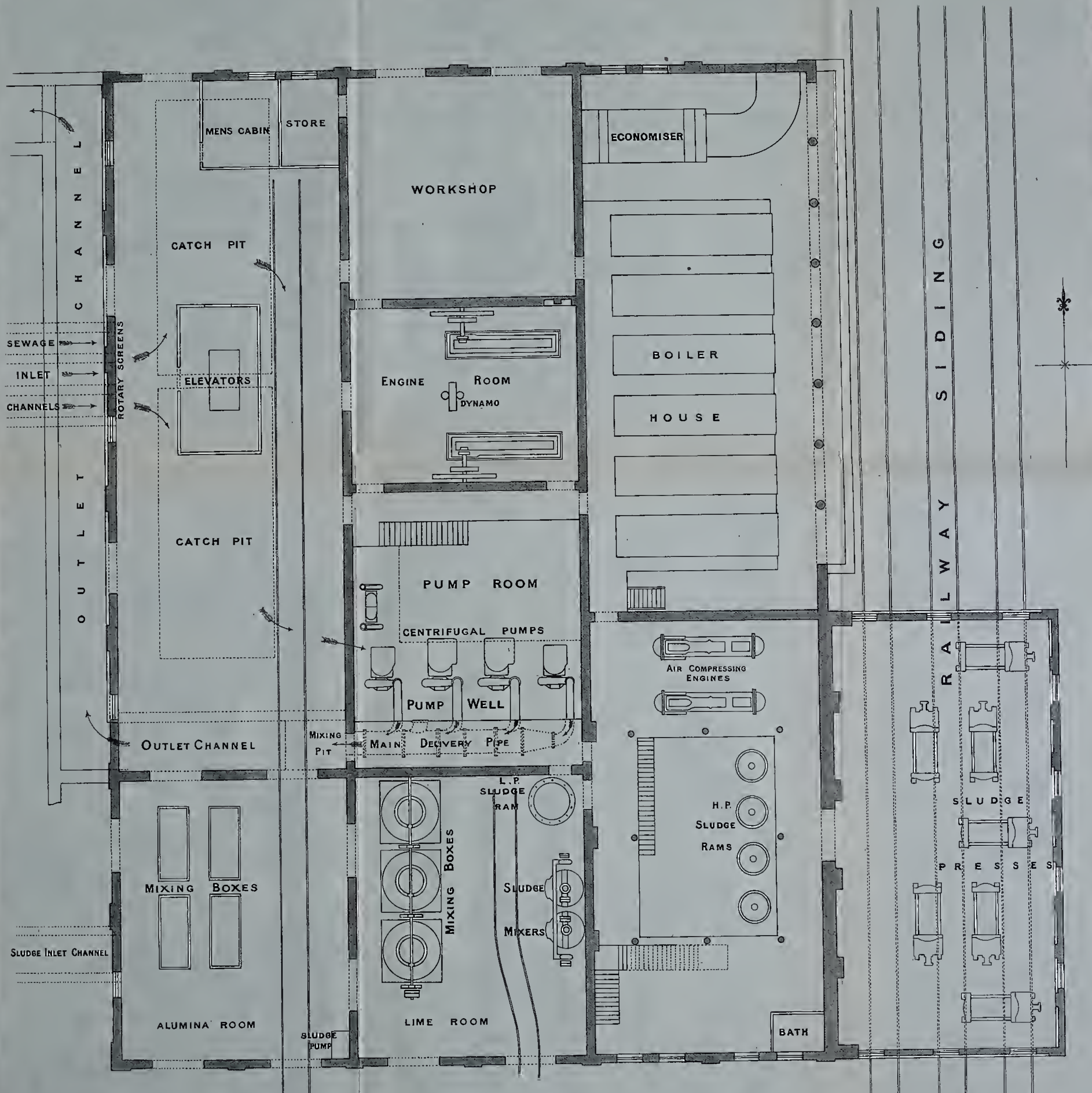
The main sewer from the city, 7ft. 6in. in diameter, is brought down the centre of Swanston Street and led into the entrance chamber, which is 17ft. × 9ft. and 16ft. 1in. deep, and situated at the north-west corner of the precipitation tanks. On the east side of the chamber, in front of three four-feet penstocks, there is a wrought-iron grid to catch heavy floating matter. From this chamber the sewage is taken into the machinery building by three 4ft. × 4ft. invert channels placed underneath the precipitation tanks and aërating beds to the west side of the catch-pits, where it has to pass through three four-feet rotary screens made of cast-steel, the bars of which are five-eighths of an inch apart. It then flows into the five-feet feed channels on the west side of the catch-pits. The level of this channel is 18ft. 6in. below floor line. Lifting plates, 4ft. × 6in., are securely attached every four feet to the rotary screens, for the purpose of taking up all floating matter, and depositing it into a wrought-iron trough placed in front at a depth of 10ft. 6in. below the floor line. The rubbish here collected is passed into a square wrought-iron self-tipping bucket, which is daily emptied into the destructor furnace. The screens work at an angle of forty-five degrees, and make fourteen revolutions per minute.

The sewage flows from the five-feet channel into the two catch-pits, each of which is 47ft. 10in. long by 20ft. broad and 10ft. deep. The V bottom of the catch-pits is 28ft. 6in. below the floor line. There are three V's in the bottom of each. A Bagshaw's endless compressed steel chain scraper, travelling twenty-eight feet per minute, conveys the solids forward to the elevator trough, the bottom of which is 33ft. 6in. below the floor line. The solids are raised by the elevator buckets

* *Vide* "Purification of Sewage and Water," by W. J. Dibdin.

GLASGOW SEWAGE WORKS.

PLAN OF MACHINERY BUILDING.



J Akerman Photo-lith. London

into a railway waggon on the floor level. Each catch-pit can be wrought separately as may be required. The sewage, free of the heavy matter, thereon flows from the catch-pits into a ten-feet channel on the east side, leading to the pump well, the depth of which is 31ft. 1in. below floor line.

The suction pipes from the centrifugal pumps are led down to within fifteen inches of the bottom. The water is raised through there into a 3ft. 9in. cast-iron pipe placed against the south wall of the pump-room, through which it flows into the mixing-pits, where the chemicals are introduced. Sulphate of alumina and lime are the precipitants presently used, in the proportion of two of alumina to one of lime. The quantities used vary according to the nature of the sewage, which is judged of by its colour.

TABLE 79.

Colour of Untreated Sewage.	Unslaked Lime: Grains per gallon.	Alumina: Grains per gallon.
Grey	5	2½
Dark Grey	7½	3¾
Very Dark Grey	10	5
Light Brown	15	7½
Blue	20	10
Brown	30	15
Dark Brown	40	20

This great fluctuation in the amount of chemicals used is due to the varying discharges from dye-works and tanneries.

There are two eighteen-inch and two fifteen-inch pumps, with a total of 350 horse-power, capable of raising one and a quarter million gallons per hour. The two six-inch pulley pumps on the east side of the pump-room discharge the sewage into the lime mixers over the sludge tank. This water is used for making milk of lime and dissolving the sulphate of alumina.

These pumps are driven from the main line of shafting, which is brought from the engine-room, where there are two pairs of compound condensing engines, each of 120 horse-power. The sewage water is used for the condensers. These engines drive all the shafting. There is also a dynamo in the engine-room, which supplies the whole light for the works.

Leaving the sewage water at the mixing-pit, which is 10ft. × 10ft. × 8ft., with a centre tongue going down to within 3ft. 6in. from the bottom, the sewage mixed with the chemicals has to pass under this tongue into an outlet channel 8ft. × 3ft. 6in., which leads to the feed channels of the precipitation tanks.

The mixing-pit is situated in the south-east corner of the main floor, over the catch-pits.

The sludge from the precipitation tanks is brought into the works by a 6ft. 6in main channel, starting at a depth of 17ft. 4in. from the west wall of the sulphate of alumina room. This channel rises three inches in 100 feet till it reaches the front of the west section of the precipitation tanks. There is a sludge channel, 3ft. 3in. wide, in front of each section of the precipitation tanks, with a fall of three inches to the 100 feet into the main channel, through which the sludge runs by gravitation into the sludge tank, which is under the sulphate of alumina room. This tank is 40ft. × 46ft. × 21ft. below the floor line, The liquid sludge is raised from this tank by a six-inch centrifugal pump into three sludge settling tanks, and allowed to precipitate. When 50 per cent. of the water is run off into the pump well, the precipitated sludge is then drawn from these tanks into a tank 46ft × 40ft. × 23ft. below the floor line under the lime-mixing room. In the north-east corner there is a low-pressure sludge ram twenty-nine feet below the floor line, capable of holding 1,800 gallons, through which the sludge is raised by compressed air into the two sludge mixers at the east wall of the lime room. Here hot lime is added to the sludge to facilitate the pressing, in the proportion of forty-six pounds of lime to the contents of the mixer, viz., 900 gallons.

In the low floor of the sludge receiving room there are four high-pressed rams, each holding 900 gallons. The sludge runs from the mixers by gravitation through a six-inch cast-iron pipe into these rams, from which it is raised by compressed air at 100 pounds to the square inch into the sludge presses. When this air has blown the sludge from the high-pressed rams, it is then transferred into the large low-pressed ram in the north-east corner of the sludge tank, thereby effecting a saving of fully 80 per cent. of compressed air, by raising sufficient sludge into the mixers to again recharge the high-pressed rams. The compressed air is made by two high-pressure engines to the north of the rams, where there is also a duplex steam pump for feeding the water into the boilers. To the south of the rams there is a bath-room for the employees.

In the press room on the top floor there are seven sludge presses, each when charged holding twenty-five hundredweight of pressed sludge cake. They deal with sixty tons of wet sludge per day, each press making forty-one cakes at a time, in about three hours. The sludge cake is dropped through shoots in the floor into railway waggons, which are immediately underneath. Here the sludge, street sweepings, and ashpit ashes are mixed together and sold for manure. A large cast-iron water and sludge tank is also on the top floor, into which the crude sludge can be raised, for the purpose of mixing with very dry ashes without the necessity of putting it through the presses.

In the boiler shed to the north of the sludge receiving room there are six 28ft. × 7ft. Lancashire boilers. The working pressure is 100lbs. per square inch. The fuel used is the coke from the filtration beds when it has become too dirty for filtration purposes. There is no difficulty in keeping up steam with this fuel. At the north end of the shed there is a Babcock & Wilcox Economiser, through which the feed water is pumped into the boilers at 200° of heat. North of the engine-room there is a workshop for doing the necessary repairs.

Returning to the sewage water as it enters the feed channels to the precipitation tanks at the north-east corner, it can be directed into either the eastern or the western double feed channels to the tanks. In each section there are twelve tanks, each capable of holding 81,000 gallons. These are wrought on the intermittent system. By opening a 2ft. 6in. × 2ft. 6in. penstock, between the feed channels and the tanks, each of the latter can be charged in seven minutes. The penstock is then closed to allow the water to precipitate, which it does in forty-five minutes. Then the floating arms are lowered to draw off the clear water, which passes across the aërating beds. When all the water has been taken off, the sludge is passed through a twelve-inch disc valve into the 3ft. 3in. underground channel, and flows into the sludge tank, as previously explained.

These precipitation tanks can be wrought on the continuous system, which, however, has the disadvantage of allowing the sludge to accumulate, and the effluent produced can never be so good; whereas, by the intermittent system here adopted, the sludge precipitated can be run off and pressed into sludge cake within five hours after it has left the main sewer.

The water from the aërating beds passes into a 17ft. 6in. channel leading to the filtering beds, which are on the west side of Swanston Street. The water syphons through below the street in three cast-iron pipes, and rises into a twenty-feet main channel, from which there are four five-feet channels branching off to distribute the water into the filters. There are twenty downward coke filters, each 40ft. × 10ft. × 3ft. 6in., through which the water passes and rises in a three-feet open channel. It again passes down through the forty sand filters, each being 40ft. × 38ft. × 2ft. 3in. The sand in these filters, when it becomes dirty on the top, is washed with precipitated sewage water, which flows by gravitation to the sand-washing machine, and thereafter used over and over again. The water then passes into the twenty-feet effluent channel, thence through five flap valves into the outlet chamber, and finally into the River Clyde. The works, as they at present stand, can deal with 10,000,000 gallons of sewage per day, or about one-fifth part of that from the entire city; but these works can be extended to treat twice that quantity. When completed the area draining into these works will be 3,465 acres, with a population of 87,800. The buildings, railway sidings, tanks, and filtering beds cover an area of nineteen acres, out of twenty-eight purchased and available. The land cost £38,000, and the buildings, tanks, and machinery an additional £67,000, or £105,000 in all.

During the twelve months 1894–1895, 2,493,315,000 gallons of sewage have been dealt with, which is equal to 11,130,870 tons 10 cwt. 2 qrs. 24 lbs., from which 127,587 tons 17 cwt. 2 qrs. of crude sludge has been extracted by precipitation, and reduced to 10,731 tons 16 cwt. by filter pressing.

The cost per million gallons of sewage is stated to be £3 8*s*.

The engineer for the works was Mr. G. V. Alsing, C.E., 180, West Regent Street, Glasgow.

Spence's "Alumino-ferric."—Lime and alumino-ferric are used as the precipitating agents at Chiswick, where the population is 21,000. The lime (seven grains to the gallon) is slaked and thoroughly mixed with water, and it is then added to the sewage and carefully mixed with it by means of an agitator and a winding channel, along which the sewage and lime flow, when it arrives at the mixing shed, where the alum in solution, in the proportion of five grains to the gallon, is added and thoroughly incorporated by further agitation. The treated sewage is then led by a distributing channel to the settling tanks. The mode of treatment was adopted on the recommendation of Dr. Tidy, and it is stated that its employment has given entire satisfaction to the Thames Conservators.

The sludge is pressed by two filter-presses by Messrs. Johnson & Co., each thirty-six inches in diameter, with twenty-four plates. Fourteen pounds of lime are mixed with each hundredweight of wet sludge before pressing, which is effected by means of compressed air. About 2,200 tons of sludge-cake is made in the year, and is removed by farmers free of cost to the Board.

Richmond Main Sewerage Board Works.—Chemical precipitation is employed at these works, the chemicals being added at different stages of the process. In the first place, a small dose of carbolic acid and iron salts is added to the sewage as it enters the pump well. When pumped up, four or five grains of lime, in the form of milk of lime, are added, and then a further addition of seven grains per gallon of sulphate of alumina, iron, etc., is made. The chemicals cost about from twenty-two to twenty-five shillings per million gallons.

The tanks are 100 feet long by 30 feet wide and 7 feet 6 inches deep, with a total capacity of 1,210,000 gallons, and can be worked on either the intermittent or continuous flow systems.

The filters are 3 feet 6 inches deep, with an area of 107 feet by 100 feet each, and are four in number. The filtering material is gravel and sand over a layer of nine-inch drain pipes. The fineness of the filtering material varies, the coarser particles being at the bottom, and the top of the filter is finished off with a three-inch layer of loam, and sown with grass. These filters have been in constant use for some years, and in 1896 all that was necessary was to renovate the surface soil.

TABLE 80.—ANALYSIS.
(CONSTITUENTS EXPRESSED IN PARTS PER 1,000.)

	Rain Sewage.	Effluent.
Free Ammonia	0·0475	0·017
Albuminoid Ammonia	0·005	0·0012
Oxygen absorbed from Standard $KMnO_4$, acting in the cold for 3 hours	50·2 c.c.	16·2 c.c.

The Natural Purification Company's System (Cosham's Patent).—The filtering tanks invented by Mr. Cosham are represented in Plate XXXIV., page 452, and are described by the patentee as follows :—

"Fig. 1 is a sectional elevation of a group of chambers constructed according to my invention, and Fig. 2 is a horizontal section of the same, on the line 5–6 of Fig. 1. Fig. 3 is a horizontal section illustrating a rectangular group of chambers more especially suitable for large towns. Fig. 4 is a detail, showing the construction of the traps for intercepting the floating sewage matter, and passing the clearer fluids on to the next chamber.

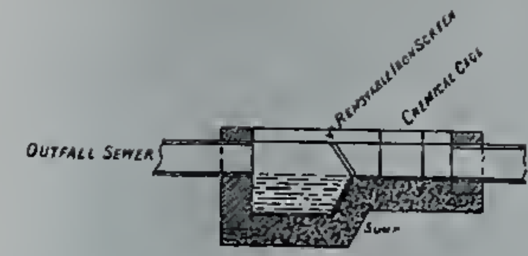
"Referring to Figs. 1 and 2, 7 is a pipe bringing the sewage to be filtered to the chamber 8. This forms the first settling chamber, the solid portions of the sewage settling in the bottom of this chamber. The lighter fluids rise in the chamber 10, and overflow, through the opening 11, into the chamber 12. Here a further settling takes place, and the fluids pass in a clearer state, through the shielded passage 13, into the chamber 14. The construction of the passage 13 is shown in elevation in Fig. 1, in horizontal section in Fig 2. This construction of the passage 13 effectually prevents the floating impurities from passing away previously to their settling, and takes only the clearest fluids from one chamber to the other. In this manner the fluids pass successively into the chambers 14, 15, 16, 17, 18, 19, and 20, precipitation taking place in each, and clear water passing away through the pipe 21, in an innocuous state.

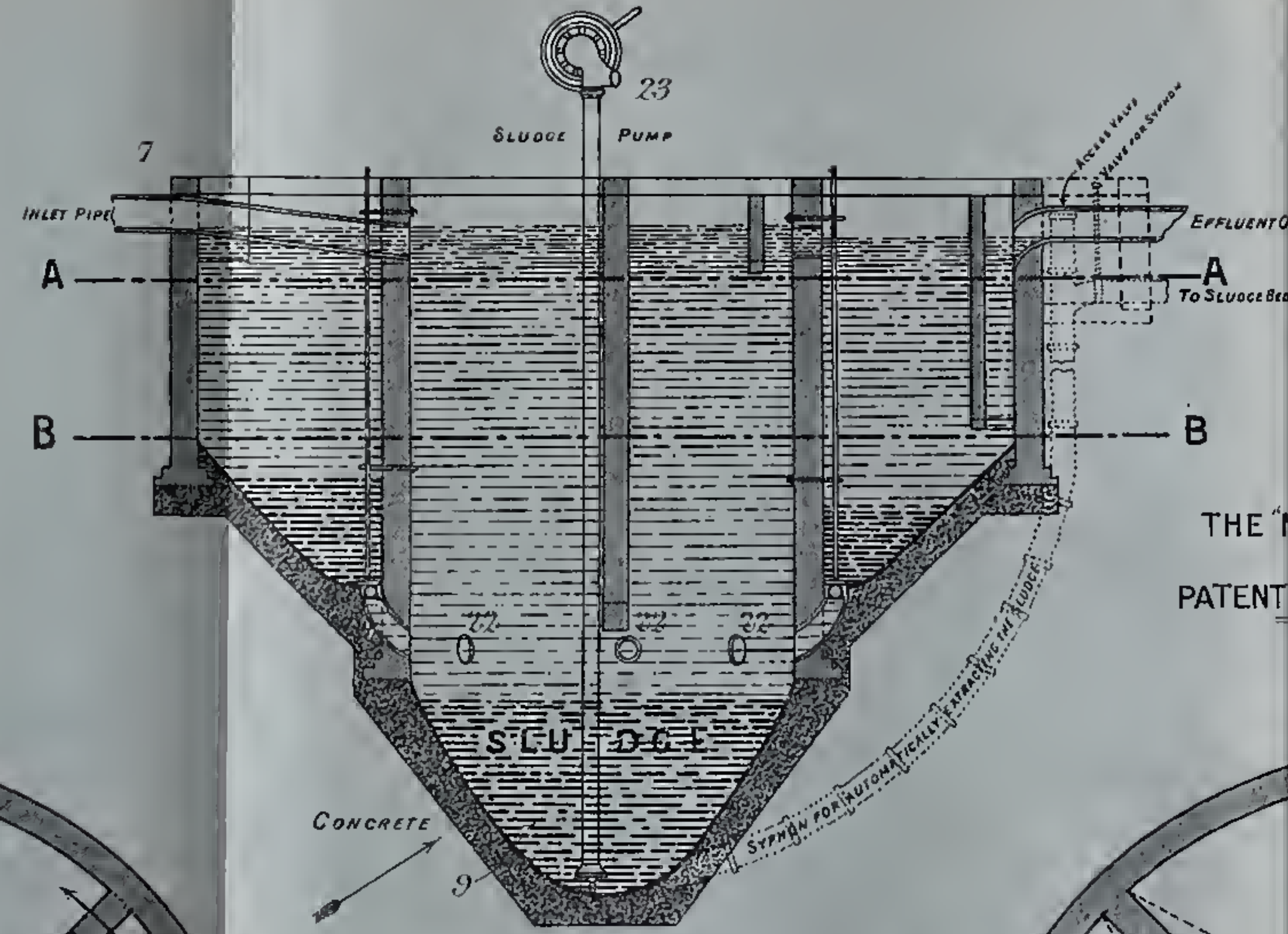
"22, 22, are passages fitted with leaden shackle valves, or other traps, leading into the chamber 9. From this chamber the solid matters may be readily removed by means of a china pump (or other pump) fitted to the pipe 23. The arrangement of rectangular chambers or tanks is on the same principle, but they are placed in sequence in a straight line. The form and arrangement of the chambers and tanks may be very much varied, to suit the circumstances under which the drainage and filtration is required to be carried out."

Nuneaton was the first to adopt the Cosham system. One of the tanks at Nuneaton was altered in 1894, and in consequence of its success the other three have been similarly remodelled, and it is stated that the conversion of the tanks at the sewage works has been attended with very great success, better results having been obtained at a considerably less cost, both in labour and chemicals, than formerly. The sewage at Nuneaton contains a large quantity of fatty matter. The system involves breaking up the solid matter and reducing it to a state fit for subsequent chemical treatment, by means of a screening chamber, at the outfall works, from which the sewage flows into the chemical chamber. The chemical cage is arranged so as to regulate the quantity of precipitant to the actual flow of the sewage, thus avoiding any waste. The precipitant employed is a slab of alumino-ferric. The sewage then flows into the first compartment of the precipitating tank, which is rectangular in form, and divided into eight compartments by means of cross walls, a connection between each compartment being obtained by means of what the patentee calls "flocculent flues," which are similar in form to chimney flues. These occur in alternate corners of each compartment, thus giving the sewage the maximum length of flow, thereby keeping it longer in contact with the precipitant. The advantage arising from the adoption of these flues is that they hold back the floating matter, and prevent the bulk of it from passing from one compartment to another. Thus by the time it reaches the last one it is practically free from suspended matter. They also cause the sewage to have a combined flow in each compartment, viz., a downward, followed by an upward, which greatly assists the precipitant in its work. The sludge is then extracted by means of sludge outlet pits, which convey it to sludge beds formed by shallow excavations in the ground, where it remains until stiff enough to be chopped into cakes, and is then carted away by farmers. Mr. E. Peacock, the Medical Officer of Health, in his report dated Nuneaton, 17th February, 1896, states :—"The result of six analyses carried out by myself showed 70 per cent. of purification after going through the 'Cosham' tank ; and although the samples of raw sewage were bad in the extreme (one containing no less than 99·8 parts of albuminoid ammonia in 1,000,000 parts of sewage), yet the effluent was bright, sparkling, and containing little or no suspended matter to go into the river, but I always recommend filtration after precipitation. We have now converted the whole of our four tanks into the 'Cosham' system (treating 500,000 gallons per day)—the only system out of many which has proved successful at Nuneaton, where we are cursed with the foulest sewage in England. We have never had a bad

PLATE XXXIV.

THE "NATURAL" PURIFICATION C^os - A. SYSTEM.
DETAIL DRAWING OF COSHAM'S
PATENT CIRCULAR AUTOMATIC PRECIPITATING TANK.

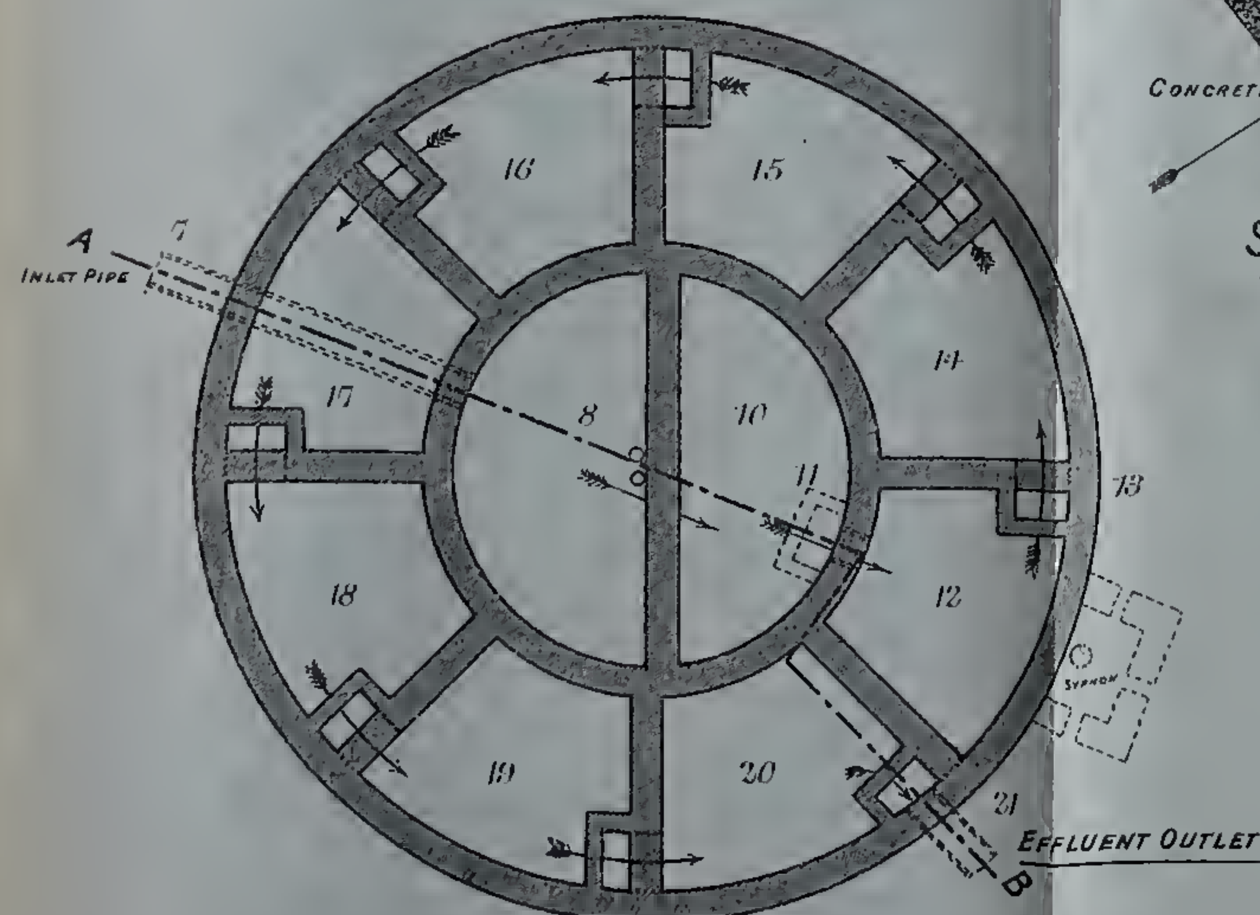




SECTION A.B.

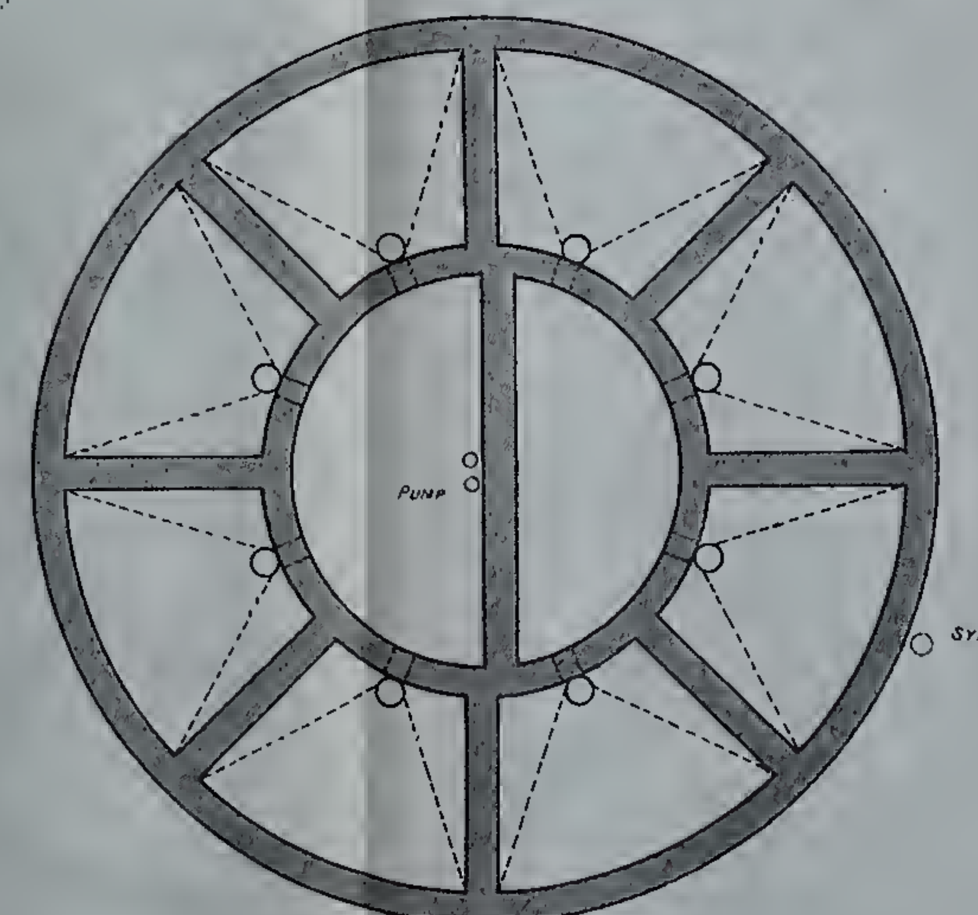
FIG. 1.

FIG. 2.



SECTIONAL PLAN AT A.A.

FIG. 3.



SECTIONAL PLAN AT B.B.

SCALE.

0 1 2 3 4 5 10 15 FEET

J. Akerman, Photo-lith. London.

effluent from the 'Cosham' tanks; with all the others we never had a good one. *Engineering*, September 11th, 1874, stated that 'Nuneaton has a sewage so strong that we affirm that no chemical process extant can battle with it. If any of your readers desire to see a most complete instance of sewage difficulty, we advise them to visit Nuneaton.' I can now say that if any one wishes to see that difficulty overcome, let them now visit Nuneaton."

The system has been adopted at Kimberley, Notts, at Tibshelf, Derbyshire, and other places, and is being introduced at Pleasley, Shirebrook, and Scarcliffe in Derbyshire, Selston, Kirkby, Raddington, and other places in Notts, etc.

The "Universal" Sewage Purification Co. (The "Ives" Patent).— The following is the description of the apparatus invented by Mr. Ives. The references are to Plates XXXV. and XXXVI., page 454, which give plans and sections of the "*Ives Patent Upward-flow self-acting continuous Precipitating Tank*":—The sewage waste or foul water enters a chemical chamber, detritus sump, and storm overflow combined at A, thence into a circular screening chamber B, such as is described in the Specification No. 16724 of 1894. This screening chamber also acts as a safety-valve to the precipitating tank, and prevents the upsetting of the contents of the same during storms by disturbing the suspended matter; both it and the chamber A are provided with storm overflows (C). The sewage, entering the screening chamber at a tangent to the outer wall, gyrates round and round, forming a whirlpool, whirling the floating solids, such as excreta, paper, and solids usually found in sewage, against the bafflers D, by which they are broken up and brought into suspension fit for chemical treatment, which takes place in this chamber. The sewage gravitates through the pipe E into the mixing and chemical race F, and additional chemical can be added in the sump G if required. After the sewage passes along the mixing race H, it falls into sumps I, then into the inlet pipes J, to the precipitating tank K, at its centre, L. It is then distributed by distributing arms, M, such as are described in the Specification No. 20744 of 1894, and out at the effluent outlet P, to the land, brook, river, or canal, as most desirable, by the channel P. Should it be necessary to further purify or filter the effluent, the valve Q is closed, and the effluent then rises in the tank K, covering the bottom of the ventilating cylinder R, forming by this means an air chamber, S. As the effluent rises this air is forced through a filter, T, thus aërating it, the filtered water passing over the wall U into the effluent channel V. By again opening the valve Q the water is lowered from the filter until its level is below the bottom of the air cylinder R, when fresh air is immediately let into the bottom of the filter. The valve Q being again closed, the water rises again, forcing fresh air through the filter as before described. This operation can again and again be repeated, according to the degree of purity required for the effluent. Should a still higher standard of purity be required, another filter, W, is provided to further filter the effluent by upward filtration. This filter is designed to act in the same manner as the filter before described. This filter is emptied for the purpose of aëration by opening the valve Z, lowering the water until it falls below the edge of the plate X, the valve is again closed, and fresh air forced through the filter. When this filter is not in use, air is sucked through the bottom of the filter by means of exhaust cowls. The precipitated sludge falls into the sludge sump (1), and is extracted by means of pumps, or syphoning through a cone suction (2), such as is described in the Specification No. 22545 of 1895, which ensures the uniform and regular extraction of all precipitated sludge from the bottom of the sludge cone (1) and the sides of the same.

The precipitant used in connection with this patent is alumino-ferric, manufactured by Messrs. Spence & Sons, in the form of slabs of convenient size, and dissolving in the sewage in proportion to the depth of immersion; thus expensive machinery is not required. The sewage effluent is passed over land in the proportion of one acre of land to 1,000 of population. In districts where land is only obtainable at prohibitory prices, and only in such cases, the "Ives" upward-flow self-aërating filter is recommended to be used with an inexpensive filtering media of coke breeze, ashes, broken brick, coal-dust, etc., thus reducing the demand for land for after treatment by one half. The following are the advantages claimed by the patentees for their apparatus :—That the combination storm overflow, detritus sump, and chemical chamber ensure a thorough mixing of the sewage, and in time of storm the storm water is partly treated and disinfected by chemicals before passing over the overflow weir. The screening chamber breaks up all the solids and brings them into suspension; it never becomes clogged; it has no moving parts to get out of order. The tank frees the sewage of all suspended matter; it has no revolving machinery or gearing or sludge pipes to get clogged. The sludge contains from eight to ten per cent. less water than produced by any other system, and is extracted without interfering in the least degree with the tank; it may be dried in the settling tank or in pits at very little expense, and is valued by farmers as a manure. It is stated that the effluent is quite bright, and remains so, is innocuous, non-putrescible. The "Ives" patents are in operation, in course of construction, or selected for adoption at over sixty places, amongst the number being Ilkeston, Alfreton, Tamworth, Gloucester, Wellington, Brightlingsea, Tring, Horncastle, Bradford, Stamford, Wollaston, Higham Ferrers, Shifnal, etc.

PLAN OF IVES' PATENT CIRCULAR PRECIPITATION TANK.

(The Universal Sewage Purification Co.'s Process.)

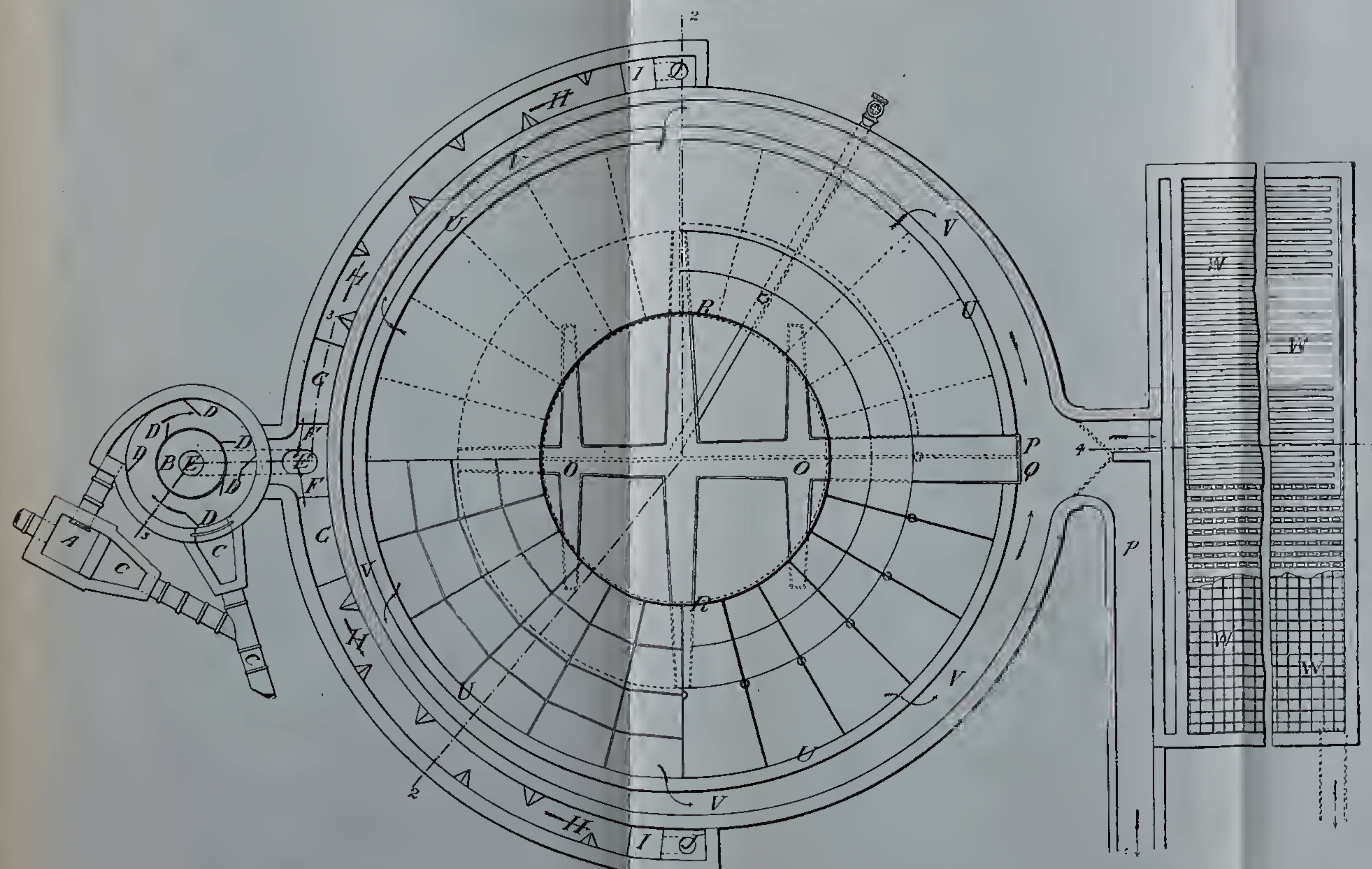


Fig. 1.

To face page 454.

Oxynite.—The Oxygen Sewage Purification Company, Limited, are now prepared to supply corporations, district, urban, or rural councils, and sanitary authorities, with the precipitant they use in carrying out the first part of their system of sewage purification. Oxynite has for its active principle crude compounds of manganese, obtained by the Company under a patented process, which enables them to put it upon the market at a price which will compare favourably with any other precipitant in use, due regard being had to its absolute efficiency and its easy application to the sewage.

Manganese compounds have long been regarded as the most efficient agents for the clarification of sewage, but their cost has hitherto prohibited their use for this purpose.

It has been found that oxynite practically deodorizes sewage, and affords sludges which have no offensive odour, and which remain free from offensive odour, even when kept in the moist state for long periods of time. The scientific explanation of this action of oxynite will be found fully set forth in the Company's pamphlet, explaining the principles of the oxygen system.

It has also been found that the sludge formed by oxynite is of a more solid and close character than those formed by other precipitating agents, affording thereby an economy in the manipulation and disposal.

It is not claimed that oxynite will produce an effluent incapable of secondary fermentation; that can only be secured by the adoption of the whole of the oxygen system of sewage purification; but oxynite may be relied upon to give a clear effluent, which, with the deposited solids, shall be odourless and void of offence.

The Company refrain from following the practice of stating the precipitating power of oxynite according to the volume of sewage which a given quantity of it will clarify, because experience has shown that, owing to the great variety in character and quality of sewages from different localities, all such statements have been found misleading; but the Company confidently claim that the efficiency of oxynite in this respect is at least equal to that of the best precipitating agents in the market.

The A.B.C. Process.—The A.B.C. process consists in the use of alum, blood, clay, and charcoal, in certain proportions, as a precipitant. The blood is now omitted.

This process is used at Aylesbury, and the sewage is converted into what is called native guano. Opinions differ about the commercial value of this product, as the special local circumstances vary so greatly.

The effluent is very pure, and is produced without any nuisance.

Prof. Robinson states that the effluent obtained by this process at Kingston-on-Thames is the best which has been produced from any precipitation process, and is allowed to flow directly into the Thames without filtration through land.

This process does not, however, seem to grow in favour among sanitary engineers.

The International Process.—In the international process a magnetic precipitant and deodorizer, called ferozone, is used, and the liquid is afterwards filtered through a polarite filter.

Ferozone, or magnetic ferrous carbon, is prepared from the same mineral that forms the basis of polarite, but is treated in a different manner. It is rich in ferrous iron, and contains also alum, calcium, sulphate of magnesia, and rustless magnetic oxide of iron.

The soluble portion of the material, when mixed with the alkaline sewage, forms a slight precipitate, and the insoluble portion (spongy magnetic oxide) assists in the rapid subsidence, and, from its porous nature, also acts as an absorbent of some of the organic matter; the particles of oxide, being porous and magnetic, part with their polarized oxygen, thereby assisting in the disinfection and deodorizing of the sewage and sludge.

Polarite is the trade name for magnetic spongy carbon; it is prepared from a peculiar description of iron found in certain parts of South Wales. In its original state it is hard, non-absorptive, and non-magnetic. It is carbonized in retorts, and treated by a patented process, and then granulated to the degree of fineness required. This mineral has been tested by Sir H. Roseoe, M.P., F.R.S., etc., and he states that the "porous nature of the oxide, its complete insolubility, and its freedom from rusting, constitute its claim to be considered a valuable filtering material." It contains no poisonous metal, is very hard, porous, and absorptive. It extracts iron and lead from water, and destroys organic matter in solution. It is a powerful deodorizer by virtue of the polarized oxygen contained in its microscopic pores. It is extremely durable and magnetic to a remarkable degree, and, notwithstanding that iron is the chief element in its construction, it will not rust. In the pores of this material a process of combustion takes place, and by this means impurities may be said to be actually burnt out of the water when brought into contact with polarite.

Mangotsfield Sewerage and Sewage Disposal.—The parish of Mangotsfield has carried out a somewhat extensive scheme of sewerage. There are in all about eighteen miles of sewers laid, consisting of 9, 12, 15, and 18-inch pipes, and extending over a large area, due provision being made for flushing and ventilation. The engineer of the disposal works is Mr. W. L. Le Maitre, C.E., of Victoria Street, Westminster, and Bristol, who was instructed by the Warmley Rural District Council to get out the necessary plans, etc., for completing the system of sewers which was commenced by another engineer, and also to prepare the necessary plans and estimates for a sewage purification installation.

These plans, etc., for the purification works and for the completion of the system of sewers, duly received the sanction of the Local Government Board—F. H. Tulloch, Esq., M.I.C.E., being the inspector who held the inquiry—and have since been carried out, the treatment proving to be most satisfactory.

The sewage is of a strong domestic character, at the same time containing refuse from a few factories, also from laundries and slaughter-houses.

Owing to self-cleansing gradients and rapid velocities having been maintained, the sewage is discharged at the works in a comparatively fresh state. The sewers are laid on the separate system, rain-water being conveyed in the old channels.

The plan and sections of the works (Plates XXXVII. and XXXVIII., page 458) show in detail the construction of the tanks, filters, etc., and also the arrangement for the removal of the sludge and subsequent pressing.

The sewage is treated by the International Co.'s process of deodorization and precipitation by means of ferozone and filtration by polarite.

Before the sludge enters the screening chamber, it receives ferozone in solution at the rate of two to three grains per gallon, according to its strength, from a mill of a simple construction, which is supplied with effluent from the filters, delivered from a storage cistern on the top of the press-house. The mill is constructed in two chambers, each having a perforated false bottom, upon one of which lump ferozone is placed. The effluent is discharged upon the top of the first chamber by means of a perforated pipe; it then dissolves a certain amount of ferozone, and is carried up through the second perforated bottom, and discharges over a sill, the outlet of which empties into the eighteen-inch main outfall sewer.

To ensure thorough incorporation with the sewage, the ferozone in solution is discharged upon a spreading-plate; by this means it is impossible for any sewage to pass without being treated. The ferozoned sewage then enters the screening chamber, which is so constructed that the two sets of scum-boards and screens may be used as desired. The scum is skimmed from the sewage and placed in the bays on either side of the chamber, and is eventually buried with the rags, brushes, etc., which are kept back by the quarter-inch and half-inch screens.

After the matter which is too coarse to pass the screens has been deposited in the chamber, the sewage is turned into either of the circular Candy upward flow precipitation tanks (Plate XXXVIII.). These tanks are twenty-four feet in diameter, and have a depth of fifteen feet six inches to overflow level, the standing capacity of each being 43,310 gallons; and as these tanks will, if required, give a good effluent when working at the rate of ten to twelve times their capacity in twenty-four hours, it will be seen that a flow of 1,040,000 gallons could be efficiently dealt with. The sewage on leaving the screening chamber enters the fifteen-inch bend which forms the connection with the horizontal inlet tube, which is again connected with the vertical tube in the centre of the tank; the sewage takes a vertical direction, and flows to within two feet of the bottom of the tank, where the heavy particles are deposited.

To avoid distributing the sludge which is overlying the bottom of the tank, a spreading-plate is attached to the vertical fifteen-inch tube.

Each tank is fitted with tongued and grooved boarding, placed vertically under the overflow channels, and reaches to a depth of ten feet, thus, as it were, making nine small tanks, the object being to secure an even flow of sewage over the whole surface of the tank, thereby securing a similar deposit of sludge.

The tanks are constructed of Portland cement, concrete, and brick-work, and are fitted with Candy's patent sludge removal apparatus. The manner in which this apparatus is worked is as simple as it is effectual. In the bottom of the tank there is a six-inch cast-iron pipe laid, having a pivoted flange in the centre of the tank, to which by means of a bend the perforated revolving arm is fixed. At the outlet of this pipe there is a six-inch watertight sluice valve, and this is connected with the Y-piece on which collars are cast for the vertical pipes; thus the sludge from either tank can be drawn off without affecting the other. At the back of the Y-piece a seven-inch sluice valve is placed, so that the tanks can be emptied should the necessity for so doing arise.

It will be seen, by referring to the sections (Plate XXXVIII.), that the actual rise for the sludge is fourteen feet three inches, and two-feet six-inch head is allowed from water level in the tanks to produce the necessary pressure to force the sludge into the perforated pipe, through the six-inch pipe laid under the tanks, and up the vertical pipes.

The method of drawing off the sludge is to open the six-inch valve, revolve the perforated pipe by means of the gearing provided; when the sludge is seen to be running thin, shut down the valve and allow the tank to rest until it is thought the sludge is sufficiently thick to again require removal. It is found necessary to draw off about once in three days.

It will be apparent that there can be no comparison between this system of sludge removal and the old principle of squeegeeing from the whole surface of a rectangular tank, the advantages gained being these, viz.:—

1. The flow of the tank is continuous.

Mangotsfield
Sewage Disposal
Works.
Plan.
Walter L. LeMaitre, Engineer,
Victoria Street, Westminster.
1898.
— Scale of Feet: —
Effluent Well
Manhole
Sand Catchpit
Polarite Filters
Gangway
Clarified Effluent Channel
Clarifier
Clarifier Chamber
Tank Effluent Channel
Precipitation Tanks
Sludge Well (Under)
Engine Room
Press Room
Stores
Emptying and Wash-Water Tank (Under)
Detritus Chamber
Chamber
Gully
To Main Road
Retaining Wall
Boundary Wall
A
B
C
E
F
G
H

2. Labour is minimised.

3. Doing away with the necessity of either letting sewage water pass over the land without further treatment, or, on the other hand, incurring the expense of pumping for re-treatment.

4. The cost of constructing circular upward flow precipitation tanks, including sludge removal apparatus, is considerably less than that of rectangular tanks of the same working capacity.

5. The sludge obtained is twice as thick.

6. One of the most objectionable points, leaving out the question of expense, is entirely done away with, viz., of men having to work in from one foot six inches to two feet of liquid sludge, when by the before-described method the work is done in a more efficient and cleanly manner, and the resulting sludge is thicker.

The sludge is conveyed from box forming the outlet of the vertical pipes, by means of an iron pipe, to a small chamber, in which two valves are built. It is then directed into either of the sludge wells under the terrace.

After sufficient time has elapsed to allow the water to rise, it (the water) is drawn off by a weir penstock, which is lowered until sludge level is reached. The top water flows into the tank-emptying manhole, and is pumped up by a centrifugal pump and discharged into the screening chamber for re-treatment.

By opening the bottom valve in well the sludge passes into the lime-mixing chamber, when enough milk of lime is added to give the pressed cake sufficient solidity to retain its shape.

The lime and sludge are then thoroughly mixed by a mechanical agitator. After this mixing the limed sludge is let into either of the rams, when compressed air is applied, forcing same from rams into the presses.

When it is desired, liquid sludge is forced up from the rams into carts outside the building, with either the addition of lime or not.

There is a ready demand for sludge in this form.

The whole of the plant is worked by a seven nominal horse-power oil engine. Provision is made for treating certain portions of the outfall site with sludge.

Having now dealt with the question of obtaining and dealing with the sludge, there remains the water, from which the solids have been removed, to treat.

After rising to the overflow level of the carriers built into the tanks, it flows into the tank effluent channel in which the six-inch inlet pipes to the Candy patent clarifiers are built.

The inlet pipes are partly submerged, and the head required to work the clarifiers is three feet four inches.

The clarifiers are five in number and cylindrical in shape, seven feet in diameter, eight feet in height, and are constructed thus :—

A perforated false bottom, containing 450 holes, is bolted to the clarifier one foot above bottom ; upon this fifteen inches of filtering material are placed. The tank effluent is admitted nine inches below the top of the filtering material, and discharges behind a sill, the top of which is three inches above sand level ; it then percolates through the layers and false bottom, passes out of the bottom pipe, and finds its outlet through trough fixed on vertical pipe.

All the suspended matter from the tank effluent is held back, producing a water clear and bright.

The question which arises is how to cleanse the clarifiers of the suspended matter retained by them. This is accomplished in the following way :—A three-way tap is placed on the bottom of the inlet pipe, so that the whole of the water can be drawn off to this level ; there is an inch tap provided on the actual bottom, so that the contents may be entirely drawn off. To cleanse the sand the clarifiers are arranged to work in couples, and by putting a head of water on any two, the next two having been emptied, then by opening the bottom valves the water returns into the empty clarifiers by their proper outlet, and upwashes the sand, etc., carrying away suspended matter. This lips over the sill, and is discharged by the three-way tap.

So that the sand may be effectually cleaned, a girder with stirrers which reach into the sand is revolved when the upwashing is taking place.

The working capacity of these five clarifiers is practically equal to that of the tanks. It is found necessary to upwash every fifteen hours.

From the outlet of the clarifiers the water may be directed on to any of the four polarite filters, which are constructed as follows :—

There is a fall of one foot from the clarified effluent channel to the side channels in the filters ; in the bottom of the filters there are channels at either end, and a central one, all of which fall to the nine-inch outlet in the bottom. There are three-inch land drains laid from the air pipes to the centre channel, a brick on edge being along the side of the channel, and cover stones placed thereon. These pipes serve a double purpose—first, they convey the water that has percolated through the filtering material to the central channel, and when this is effected they form fresh air carriers, and so aërate the bed. The bottom layer of material is 6 inches of 3-inch broken stone, followed by 3 inches of 1-inch to 1½-inch ditto, 3 inches of gravel, 3 inches of grit, 9 inches of grit and polarite, and 6 inches of sand, running to 9 inches in the centre.

There is an area of 480 square yards, and 1,500 gallons per square yard can be treated in twenty-four hours.

The clarified effluent undergoes a change in its passage through the polarite filters. The whole of the dissolved organic matter in the water is burnt during its contact with the polarite, and passes off as ammonia, carbonic acid, and water—purification which, as is shown, is effected by oxidation to the extent of 98 per cent.

The filtered water passes into the effluent well, which is three inches below the bottom of the filters. By an arrangement of upper and lower valves, any specific filter may have a head of water put on it, and upwash any other that may be desired. This will only have to be very occasionally done, owing to the use of clarifiers. The wash-water from the clarifiers and the filters is run back to a sump, pumped up, and discharged into the screening chamber for re-treatment.

There are two outlets from the effluent well, nine inches and twelve inches, which convey the water into the effluent carriers. The whole of the water from the filters is put over land (Plate XXXIX., page 462), and eventually collected and discharged into the River Frome. The effluent, in passing over the land, rapidly nitrifies, and proves the impossibility of secondary putrefaction. Plate XXXIX. also includes a general view of the works.

The total cost of these works, including a manager's cottage, is £6,350, and a considerable saving has been effected on the estimate.

The following reports give the results of the use of polarite filters, etc., at a few other places :—

TABLE 81.

Analysis of Effluent, etc.—

Result of Analysis of the Sewage Effluent at Ashley Down Sewage Works, sampled Sept. 18th, 5 p.m.

LABORATORY, 4, QUEEN SQUARE, BRISTOL,

Sept. 21*st*, 1897.

Tank.			
7·040	Saline ammonia	0·912	per 100,000
0·996	Albuminoid ammonia	0·088	,, ,,
	Oxygen (4 hours' absorption)......	0·382	,, ,,
	Total solids............................	106	,, ,,

This is a very good effluent, clear and free from any offensive odour.

The filter-beds are in first-rate order and doing their work well, as the figures in the left-hand column show ; indeed, I have never known these filter-beds work so well.

The purification of albuminoid ammonia being about 92 per cent. on the tank effluent, which would work out to about a 96 per cent. purification on the raw sewage.

Yours faithfully,

(Signed) CHAS. J. WATERFALL, F.C.S., F.I.C.

NOTE.—Mr. Waterfall further reports that the last series of analyses made in September by him showed the crude sewage to contain 2·33 of albuminoid ammonia in parts per 100,000, whilst the purified effluent contains ·088 parts per 100,000.

The analyst further adds, "The samples were taken by myself, my visit being an entirely unexpected one."

The polarite and sand filters have been in operation here for two years.

The Hastings water supply is purified by means of polarite, and the eminent analyst, Dr. Dupré, reports that "the waters are of great organic purity and of the highest class."

(Copy.) THE CLIFF, HIGHER BROUGHTON, MANCHESTER,
June 24th, 1897.

MR. ALDERMAN HIBBERT,
Chairman, Sewage Committee, Chorley.

Dear Sir,

On the 31st inst. I received from you a set of sealed samples collected on the same day, in your presence, at the sewage works of the Chorley Corporation, by Mr. James Leigh, of the Borough Engineer's Department, viz. :—

No. 1. Averaged sample of crude sewage as it entered the works prior to the addition of the precipitant ferozone from 9 a.m. to 12.30 noon, representing a tank of 140,000 gallons of sewage.

No. 2. Sample of the same tank effluent after precipitating four hours.

No. 3. Sample of coke breeze filter effluent from the same.

No. 4. Sample of polarite filter effluent from the same.

I have analysed these, with the following results :—

TABLE 82.

In Parts per 100,000.	No. 1, Crude.	No. 2, Tank Effluent.	No. 3, Coke Breeze.	No. 4, Polarite Effluent.
Free ammonia	9·6	6·0	3·6	·12
Albuminoid ammonia	6·8	·56	·40	·10
Oxygen absorbed in 4 hours for 1 gallon	15·2	1·9	1·1	·18

You will see that the "polarite" is a very high-class effluent.

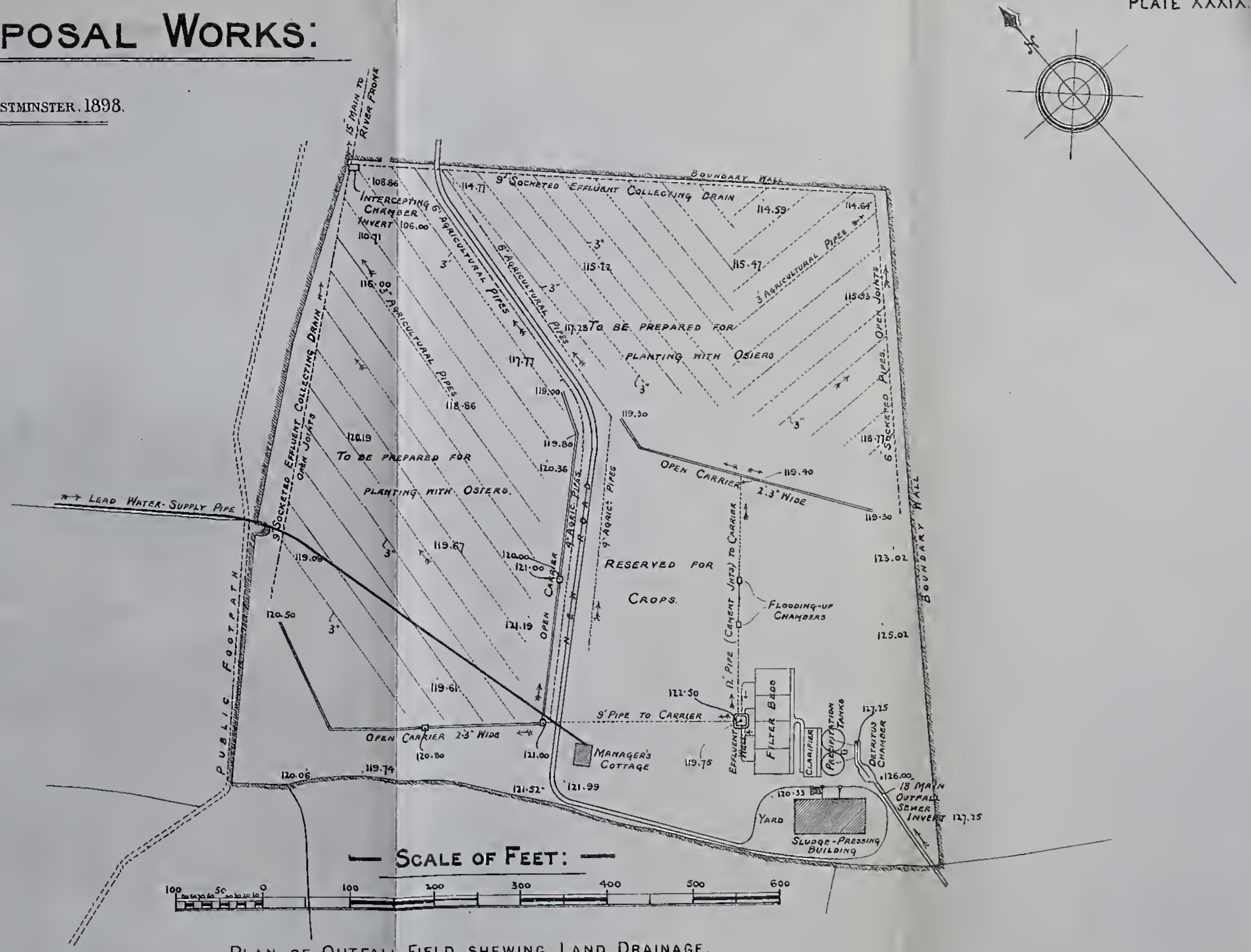
Yours truly,

(Signed) J. CARTER-BELL,
Analyst for the County of Chester, Borough of Salford, etc.

MANGOTSFIELD SEWAGE-DISPOSAL WORKS:

WALTER L. LE MAITRE, ENGINEER, VICTORIA STREET, WESTMINSTER. 1898.

GENERAL VIEW OF WORKS.



PLAN OF OUTFALL FIELD, SHEWING LAND DRAINAGE.

Duplicate samples were also analysed by Dr. Angell, County Analyst, Southampton, who reported on July 8th respecting the coke breeze and polarite effluents as below :—

(Copy.) COUNTY LABORATORY, SOUTHAMPTON,
July 8th, 1897.

Re Chorley Effluents of June 21st, 1897.

The coke breeze effluent has now developed a copious growth of sewage fungus, and stinks most horribly.

The polarite effluent is sweet and bright as at first. Both samples were kept stoppered up in my laboratory side by side.

Yours faithfully,

(Signed) ARTHUR ANGELL, Ph.D., F.I.C.

Conder's Sulphate of Iron Process.—Sulphate of iron was advocated by the late Mr. F. R. Conder, M.I.C.E., as a precipitant. The process consists, briefly, in treating the sewage of each house to a dose of solution of iron, by which it is claimed "that the putrescible, or putrescent, matter that it contains is immediately split up into its innocuous elements ; the liberation of gases ceases, and the mineral matter thus set free subsides as a fine black silt, that is easily swept along by a current of half a mile per hour."

The solution of iron is to be added to the sewage of each house by means of an instrument termed a ferrometer (Fig. 3, Plate XL., page 464), through which a small stream of water constantly flows, and by dissolving the sulphate of iron, carries it into the sewers, a slice of lemon being placed every week in the instrument to add a vegetable acid. In addition to this, small receptacles, or trays, of sulphate of iron are provided in the manholes, through which water is allowed to flow, or they may be placed in the sewer, as shown in Figs. 4 and 5.

Fig. 3 of the same plate illustrates the ferrometer above mentioned. It consists of a glass tube, marked A, in which the sulphate of iron is placed ; there are three holes at the bottom of this tube, which admit of the iron being dissolved by the water in the porcelain cup, B, into which the tube dips. The porcelain cup is partitioned off into two unequal parts by a perforated tin-plate at C.

The depth of the dip of this tube, A, can be regulated at pleasure by a brass clamping collar, G, so as to regulate the quantity to be consumed.

Water is admitted into the porcelain cup through the tap, E. The liquid flows off through the partition into the smaller compartment, from which it escapes by the pipe, D, to the drain or w.c. pan, etc. In the new pattern ferrometer an extra tap, F, is supplied at the bottom of the porcelain cup for discharging the iron disinfectant over sinks, etc. The tube contains 3 lbs. of prepared sulphate of iron, and by regulating the depth of immersion, and flow of water, this quantity may either be dissolved in 12 hours, or may last for three weeks.

The proper quantity to be dissolved depends upon the number of contributors to the sewage to be treated.

Soft, or warm water, dissolves the copperas, or sulphate of iron, more rapidly than hard or very cold water.

In most cases it is recommended that one ferrometer should be fixed in the highest w.c. in the house, and that a second should be fixed to command the back kitchen sink, in order to extinguish any smell arising from the water used for boiling vegetables, etc.

The tap, E, may be connected with a small cistern of four or five gallons capacity, so as to disconnect it from the main supply of the house, but this is said to be by the manufacturers, Messrs. Filmer & Mason, Guildford, unnecessary, and that it may have a direct connection with the house-water supply.

This system is believed to have answered well on a small scale, *e.g.*, at Chichester barracks, but there are evidently practical difficulties in the way of its adoption for the drainage of a town.

The chief difficulty is the accumulation of deposit in the sewers, consisting of a mineral matter which, although inoffensive, might, in channels of low velocity, form an obstruction to the ordinary flow. To get over this difficulty, catch-pits have been recommended, which, if cleared out once a week, need only be of a capacity of 30 cubic feet per 1,000 inhabitants.

The expense of installation and royalty, exclusive of cost of catch-pits, is £36 5*s.* per 100 inhabitants.

The cost of chemicals is about 6*d.* per unit of population per annum.

The cost of labour is an essential item in an estimate for this system, as it is necessary to charge the cylinders, or other apparatus, with copperas once, twice, or thrice a day, according to circumstances.

The cost of removal of precipitate from the catch-pits above quoted is said to be covered by the value of the precipitate obtained.

The treatment of Chichester barracks is effected by porcelain cylinders, placed in a 10-gallon iron tank, with a regulating outfall pipe leading into the barrack sewer (see Figs. 1 and 2, Plate XL.), just before it leaves the barrack, 680 feet from the outfall. The sewage runs into a 15-inch pipe, which, on leaving the barrack, falls 12 feet 3 inches in the distance (680 feet) above mentioned, and discharges its contents into an open ditch.

TREATMENT OF SEWAGE BY THE IRON PROCESS.

Adaptation of Iron Process.

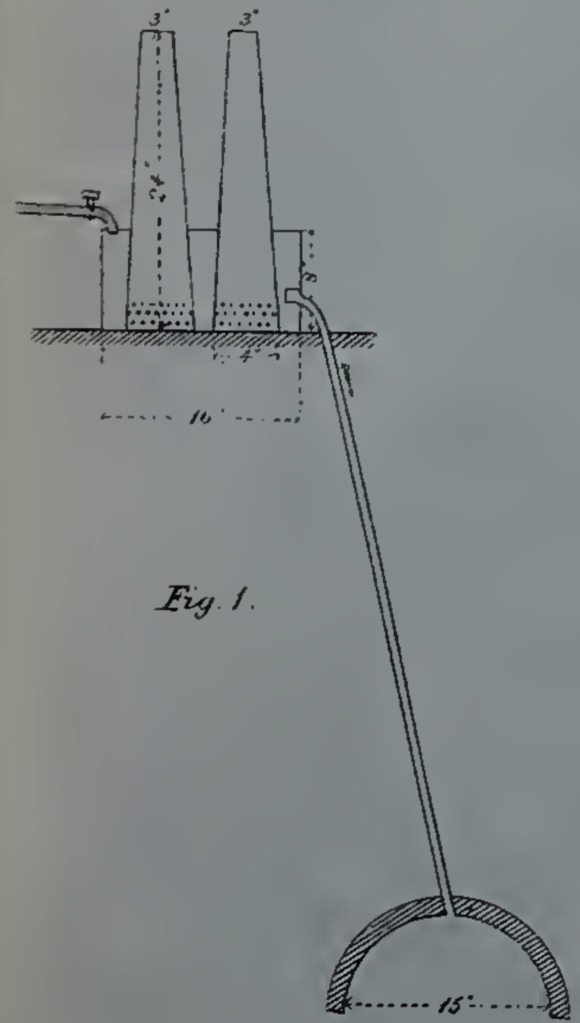
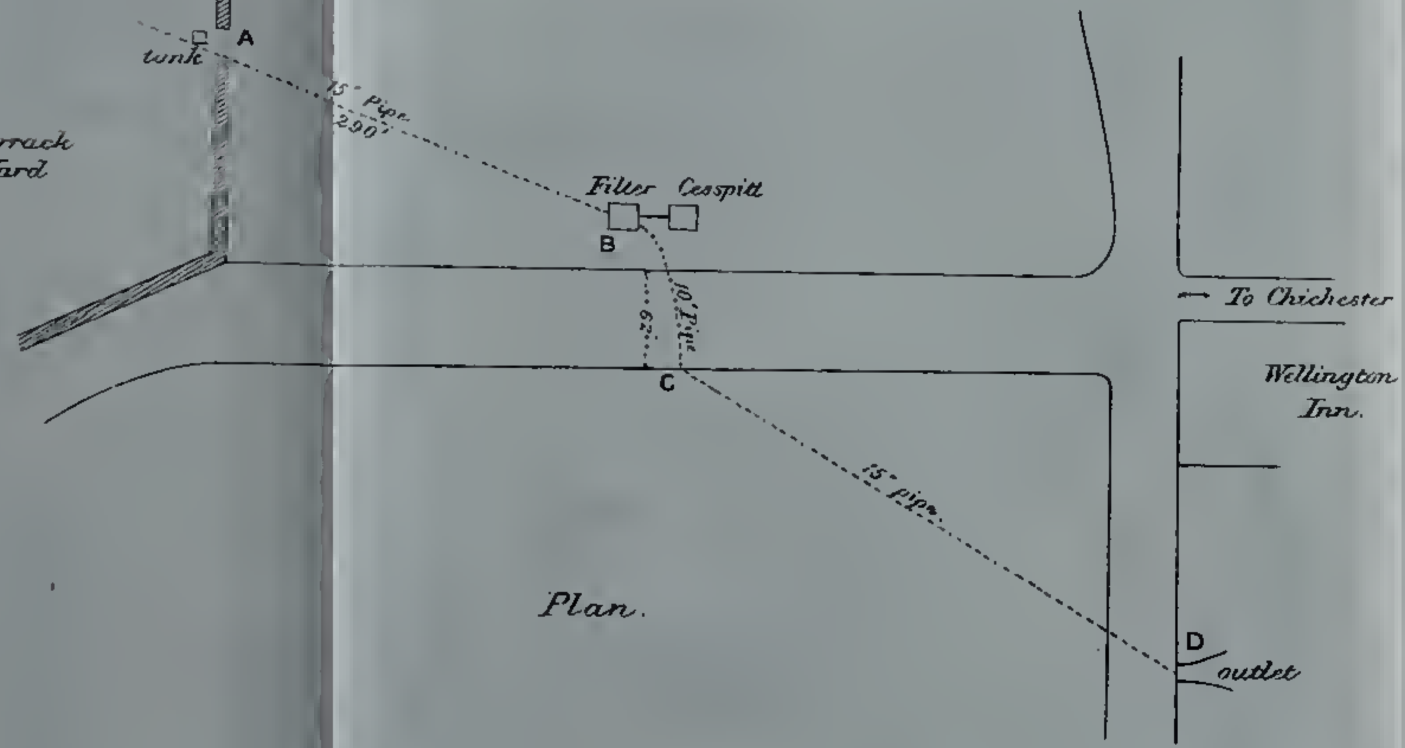


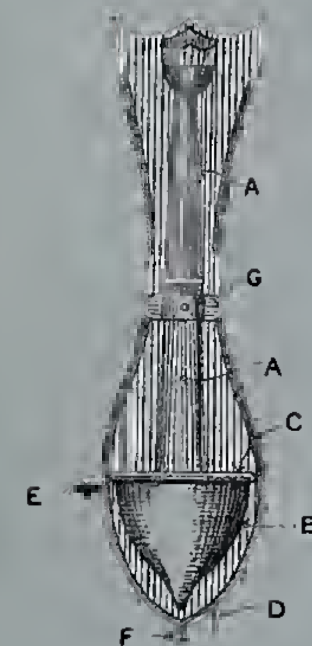
Fig. 1.

Fig. 2.



Plan.

Fig. 3.



A. Glass tube.
B. Porcelain cup.
C. Tin plate division.
D. Escape pipe.
E. Water tap.
G. Brass clamping collar.

Ferrometer.

Fig. 4.

Elevation.

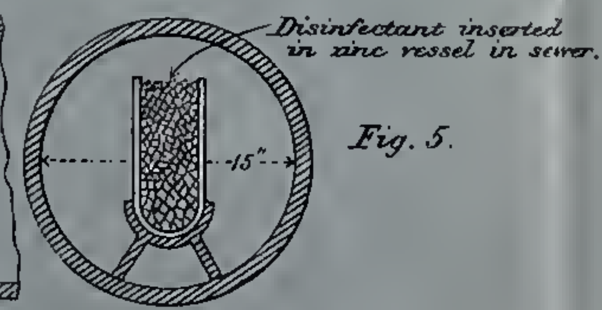


Fig. 5.

Section.

J. Akerman, Photo lith London

The ordinary population is about 500 in all. The flow from the sewer pipe was gauged in February, 1886, at 15,000 gallons per day. The analysis of this flow was 15·62 grains of organic, and 27·96 grains of inorganic matter in each gallon of sewage.

After the apparatus above quoted had been in operation six weeks, samples of the effluent, on analysis, were found to contain ·63 grains of organic, and 2·87 grains per cent. of inorganic matter, in suspension.

The author tried this process in Bermuda, with very satisfactory results. It kept the sewers clean, preventing coating and the formation of sewer-gas.

The Hermite Process.—This system is in operation in Ipswich. The engineers are Messrs. Patterson & Cooper, 68, Victoria St., Westminster. Electricity is employed to produce deodorising and antiseptic fluid, either from sea-water or from a solution of magnesium and sodium chlorides. The resulting liquid is then applied directly to the drains instead of at the outfall as in other systems, with the exception of Conder's. At Ipswich the antiseptic fluid is turned into the head of the main sewer, but another method suggested is to supply it to all houses for the purpose of flushing the w.c.'s and drains. The process depends on the formation of nascent oxygen held in suspension by hypochlorite of magnesia, obtained by passing a current through the sea-water between platinum and zinc electrodes. The oxygen thus obtained is the antiseptic.

Dale's Muriate of Iron Process.—Sulphate of alumina and perchloride of iron have long been known as disinfectants of sewage, and a concentrated solution of the latter has given good results, under a system known as Dale's muriate of iron process.

Comparative Advantages of the different Precipitants.—The following are extracts from the report of the State Board of Health of Massachusetts, giving the general view of the results of their investigations (pp. 786—791) :—

"The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways.

"Precipitation by copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done a good result is obtained. The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide. Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage.

"The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipitate alum at once.

"It is quite possible that the same process would not give equally good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another.

"In the later experiments, from 25 to 43 per cent. of the soluble organic matter, as shown by the albuminoid ammonia, and loss on ignition, was removed by copperas, ferric sulphate, or alum, costing from 30 to 40 cents per inhabitant annually. In addition to this, all of the suspended matter was removed.

"The average composition of sewage used for these experiments, and also the average analysis of 262 samples of sewage, from November 1st, 1888, to October 31st, 1889, evenly distributed throughout the year, is as follows :—

TABLE 83.

"AVERAGE COMPOSITION OF THE SEWAGE USED.
PARTS PER 100,000.

	In the Experiments.	For the Year.
Turbidity	·65	
Loss on ignition, total	25·4	19·1
In solution, filtered	16·6	12·1
In suspension, difference	8·8	7·0
In suspension	35 per cent.	37 per cent.
Albuminoid ammonia, total	·66	·53
In solution, filtered	·39	·267
In suspension, difference	·27	·263
In suspension	41 per cent.	50 per cent.
Free ammonia, total	1·83	1·82
In solution	1·81	1·77

"In the sewage used for the experiments, 41 per cent. of the organic matter, as shown by the albuminoid ammonia, was in suspension, while in the year's sewage the proportion was 50 per cent. Let us take 45 per cent. as the average. If we can remove 30 per cent. of the soluble organic matter, and all of the suspended, we shall leave only 70 per cent. of the 55 per cent. soluble organic matter, or 38 per cent. of the whole ; while, if we remove 40 per cent. of the soluble organic matter, the amount left will be only 33 per cent. of the whole.

"Of the other substances present, the insoluble inorganic matters, mainly sand, are removed almost completely, while the soluble salts, including chlorine and free ammonia, are not affected in the least, excepting that the acid of the precipitant remains in solution, in combination with the alkali of sewage. A very large proportion of bacteria and the other organisms is removed. This is all that can be done by chemical precipitation."

Relations of Sewage and the Effluents from Chemical Precipitation to the Growth of Bacteria and Algæ.—"When a nuisance is produced by sewage in any way, the direct cause is usually the development of organisms fed by the organic matter and nitrogen compounds of the sewage. To secure the absence of organisms in any pond or stream where food is present, is a hopeless task. It thus happens that, while the organisms are the real cause of the trouble, their removal from sewage is often of less importance than the removal of the matter in the sewage on which they feed. The proportion of organic matter removed does not necessarily represent the proportion of food for organisms removed, for some kinds of organic matter are no more suitable food for bacteria than is sawdust for horses. An effluent from a sewage filter, where nitrification is complete, containing 2 per cent. of the total organic matter of the sewage, will not serve as food for bacteria, because it has been worked over already by bacteria, in the filter, and nearly everything available has been removed. If, on the other hand, sewage is mixed with fifty times its volume of pure water, so that it contains the same amount of organic matter as the effluent, the bacteria will increase enormously for a few days. From this point of view, the effluent is many times purer than is indicated by the ratio of its organic matter to that of the sewage.

"With sewage precipitation the case is entirely different, for here there is no bacterial action. There is, however, some reason to think that the organic matter left is not so good a food, and therefore not so dangerous, as that removed. Sewage settled alone will keep turbid with organisms, and in a day or two masses of zoöglœa (dead or resting bacteria) separate from it. Sewage precipitated by either copperas, ferric sulphate, or alum, in suitable quantities, has repeatedly remained so clear that the bottom of the barrels could be distinctly seen through more than two feet of liquid, for one or two weeks. In these cases no flakes of zoöglœa, so characteristic of untreated sewage, have been seen, and the odour is much less than that of sewage alone.

"This question of the quality of the organic matter left by precipitation has not been sufficiently investigated, but the indications are that it is more objectionable than the same amount in the effluents from sewage filtration through sand, but less objectionable than that in sewage.

"When untreated sewage is put into a small stream or pond, it often happens that the suspended matters settle out, forming considerable deposits, which, putrefying out of contact of the air, give rise to very offensive gases. It is hardly probable that well-precipitated sewage would do this, for almost no suspended organic matter is present when it leaves the settling tank, and very little soluble matter is precipitated on exposure to the air.

"Another nuisance which might be caused by putting precipitated sewage into a stream or pond is the growth of algæ—green plants fed by the ammonia of sewage. It may be said, however, that this growth would be no greater than that caused by the crude sewage, and probably not much greater than that caused by filtered sewage, for in the latter case, while the ammonia is removed, nearly an equivalent of nitrate is formed, as this serves as food for algæ almost as readily as ammonia.

"A number of fishes were put into precipitated sewage. In each case the fish died within five minutes. This sudden death cannot be due to the chemicals used, for it was found that the fishes lived for a considerable time in solutions of the chemicals much stronger than those present in the sewage. The fishes died for want of air; sewage contains no dissolved oxygen, and, if any is absorbed from the air, it is quickly taken up by the organic matter. The precipitated sewage also contains no oxygen.

Conclusions.—"Using lime as a precipitant, we have found that there is a certain definite amount of lime, depending upon the composition of the sewage, which gives a better result than less, and as good or better result than more. This amount of lime is that which exactly suffices to form normal carbonates with all the carbonic acid of the sewage. It is possible in a few minutes, by simple titration, to determine approximately the amount of uncombined carbonic acid present in sewage, and how much lime will be required to combine with it. It is also possible to determine in a similar way, after mixing, whether enough or too much lime has been added. The amount of lime required by Lawrence sewage averages about 1,600 pounds per million gallons.

"Ordinary house sewage is not sufficiently alkaline to precipitate copperas, and a small amount of lime must be added to obtain good results. The quantity of lime required depends both upon the composition of the sewage and the amount of copperas used, and can be calculated from titration of the sewage. Very imperfect results are obtained with too little lime, and when too much is used, the excess is wasted, the result being the same as with a smaller quantity.

"After mixing the sewage with both copperas and lime, if enough or too much lime has been used, the mixture will colour phenolphthalein red, while, if too little has been used, no colour will be produced. The test can conveniently be used by people having no knowledge of chemistry, and affords an easy and very accurate method of applying enough lime, and of avoiding a useless excess.

"Using in each case a suitable amount of lime, the more copperas used the better the result ; but with more than one-half a ton per million gallons, the improvement does not compare with the increased cost

"Some acid sewages contain a considerable amount of iron in solution, and in these cases precipitation by lime is really the rendering available of the copperas already in the sewage, and so is properly classed as an iron treatment rather than a lime treatment. In this case the reaction with phenolphthalein shows the presence of enough lime.

"In precipitation by ferric sulphate and crude alum, the addition of lime was found unnecessary, as ordinary sewage contains enough alkali to decompose these salts. Within reasonable limits, the more of these precipitants used the better is the result, but with very large quantities the improvement does not compare with the increased cost.

"Using equal values of the different precipitants, applied, under the most favourable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime used together, while lime and alum each gave somewhat inferior effluents. The range of these results was, however, comparatively narrow ; and it may be that with sewage of a different character, or with variations in the prices of the chemicals, it would be advantageous to use copperas with lime, or even alum. When lime is used there is always so much lime left in solution that it is doubtful if its use would ever be found satisfactory except in case of acid sewage.

"It is quite impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand.

"It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation, with a proper amount of an iron or aluminum salt, and it seems probable that, in some cases at least, if the process is carried out with the same care as is required in the purification of sewage by intermittent filtration, a result may be obtained which will effectually prevent a public nuisance."

VI. **Electrolysis.**—Precipitation by electrolysis, which is also known as "Webster's" process, for the electrical purification of sewage has been tried successfully at Crossness, and gives very promising results both as regards the purity of the effluent and the eventual cost of the process.

Webster's Process for the Electrical Purification of Sewage.—The following is a description of the method employed by Mr. Webster :—

The first experiments were conducted with platinum plates, but their cost was prohibitive, besides which there was a very slight action on the positive plate pointing to its ultimate destruction ; there was no precipitation in the sewage of the matters in suspension, and, as this is absolutely necessary, the more complete this is, the better the ultimate result. It was found that oxidable plates produced the desired results. These plates must be of such material that they have no poisonous after effects, either on land or in rivers. The metals should be either aluminium or iron, but the first-named is out of the question owing to its cost, and then iron, besides having the advantage as regards price, has, in the form of oxide, many valuable qualities, one of the chief being that sulphuretted hydrogen cannot exist when ferrous, or ferric, oxides are present.

The success of the laboratory experiments was such that Mr. Webster asked for and obtained permission to set up plant at Crossness, near the southern outfall of the Metropolitan sewage into the Thames, for the purpose of demonstrating on a practical scale the advantages of the process, and it was conclusively proved that cast-iron plates of the commonest quality employed as electrodes give the best results. For treating sewage, or impure water, the fluid is allowed to flow through suitably constructed channels containing iron plates set longitudinally, the alternate plates being connected respectively with the positive and negative terminals of a dynamo. The sewage, or impure liquid, in its passage through these channels becomes entirely split up by the electric action. The matters in suspension in sewage, and part of the organic matter, are not only removed by precipitation, but the soluble organic matter is oxidized and burnt up by the nascent oxygen, and chlorine oxides evolved, and this oxidization may be carried to any extent, according to the amount of purification required.

The fact that water is easily decomposed, provided the current of electricity is of sufficient intensity, and also that the effects produced are precisely in accordance with the chemical equivalents of the substances electrolysed, is practically the explanation of the whole system, for the chemical changes that take place in sewage when it is electrolysed depend chiefly on the well-known fact that sodium, magnesium, and other chlorides (which are always present in sewage) are split up into their constituent parts. At the positive pole the chlorine and oxygen given off combine with the iron to form a salt, which Mr. Webster believes is a hypochlorite of the metal, but it immediately changes into a chloride, which, in its turn, is deprived of chlorine to form ferrous carbonates and oxides. During the chemical action carbonate of iron exists in solution, and its formation is due to the presence of carbonates in the sewage, chiefly carbonate of ammonia. In samples that are absolutely free from dissolved oxygen the ferrous oxide in the white form is precipitated, and, on shaking up with air, it changes to the usual pale green colour. The carbonate of iron at the same time being oxidized, the ultimate precipitate is red, known as ferric oxide (Fe_2O_3), and it is noticed that sometimes this changes, after a time, back again to the ferrous state (FeO), thus showing that it has acted as a carrier of oxygen to the organic matter present.

The organic matter in solution of the particular sewage treated with ·23 ampères per gallon showed a reduction of 61 per cent.

In other cases a purification of as much as 87 per cent. was obtained. If a lesser purification be sufficient, the horse-power can be proportionally reduced. During another run that lately took place at Crossness, 19 horse-power was sufficient for the treatment of one million gallons in 24 hours, the resulting purification of organic matter in solution amounting to 50 per cent.

The great reduction of organic matter in solution obtained by electrolysis cannot be produced by chemicals except at a prohibitive cost, besides entailing a large addition to the bulk of sludge and inorganic matters in solution, which inevitably produce secondary putrefaction. A point of immense importance is that by this process the bulk of the sludge is reduced to a minimum. Where suitable land is available for irrigation or filtration, a smaller reduction of organic matter in solution is sufficient, settling tanks are unnecessary, and the expense of the electrical treatment can be much reduced.

Where suitable land is not available for this purpose, settling tanks are required. This effluent contains about three grains of suspended matter per gallon, which, as it consists almost entirely of iron oxide, is quite innocuous. But where this is objectionable from a sentimental point of view, it can be entirely removed by filtration through a few inches of sand, and the effluent is then fit to be discharged into a stream. Sir Henry Roscoe's report shows that the unfiltered effluent is in no degree less pure chemically as regards organic matters than the filtered effluent.

Where a still higher degree of purification is required, it can be obtained by using an electric filter, which is arranged as follows:— Alternate layers of small coke free from sulphur are separated, either by layers of sand or perforated tiles; by suitable connection these layers of coke form positive and negative electrodes—the first layer of material being sand, so as to mechanically separate matters in suspension. It is impossible for disease germs to propagate, owing to the nascent oxygen and chlorine produced when the filter is in action.

The bacteria question is one which has probably still to be settled; but being anxious to have some information as to the action of the iron compound produced by electro-chemical decompositions, Mr. Webster had some experiments carried out, with the result that after a given treatment the whole of the bacteria were killed. In the case of experiments carried out in Paris with ordinary treatment by means of iron electrodes, the results were as follows :—

	Raw Sewage.	Effluent.
Organisms per cubic centimètre ...	5,000,000 ...	600

Another experiment, in which the effluent was treated still further, so that a slight odour of oxide of chlorine was perceptible, destroyed all organisms, and the liquid remained sterile.

A thorough investigation of the process was carried out at Webster's experimental works by Sir Henry Roscoe, M.P., F.R.S., and by Mr. Alfred E. Fletcher, F.C.S., F.I.C. (H.M. Inspector under the Rivers Pollution Prevention Act for Scotland), the quantity of London sewage operated upon in each experiment being about 20,000 gallons.

Reports on.—Sir Henry Roscoe reports as follows :—

"The reduction of organic matter in solution is the crucial test of the value of a purifying agent, for unless the organic matter is reduced the effluent will putrefy and rapidly become offensive.

"I have not observed in any of the unfiltered effluents from this process which I have examined any signs of putrefaction, but, on the contrary, a tendency to oxidize. The absence of sulphuretted hydrogen in samples of unfiltered effluent which have been kept for about six weeks in stoppered bottles is also a fact of importance. The settled sewage was not in this condition, as it rapidly underwent putrefaction, even in contact with air, in two or three days.

"The results of this chemical investigation show that the chief advantages of this system of purification are :—

"*First.*—The active agent, hydrated ferrous oxide, is prepared within the sewage itself as a flocculent precipitate. (It is scarcely necessary to add that the inorganic salts in solution are not increased, as in the case where chemicals in solution are added to the sewage.) Not only does it act as a mechanical precipitant, but it possesses the property of combining chemically with some of the soluble organic matter, and carrying it down in an insoluble form.

"*Second.*—Hydrated ferrous oxide is a deodorizer.

"*Third.*—By this process the soluble organic matter is reduced to a condition favourable to the further and complete purification by natural agencies.

"*Fourth.*—The effluent is not liable to secondary putrefaction."

Mr. Alfred E. Fletcher reports as follows :—

"The treatment causes a reduction in the oxidable matter in the sewage, varying from 60 to 80 per cent. The practical result of the process is a very rapid and complete clarification of the sewage, which enables the sludge to separate freely.

"It was noticed that while the raw sewage filters very slowly, so that 500 cubic centimètres required 96 hours to pass through a paper filter, the electrically treated sewage settled well and filtered rapidly.

"Samples of the raw sewage having but little smell when fresh, stank strongly on the third day. The treated samples, however, had no smell originally, and remain sweet, without putrefactive change.

"In producing this result two agencies are at work ; there is the action of electrolysis, and the formation of a hydrated oxide of iron. It is not possible, perhaps, to define the exact action, but as the formation of an iron oxide is part of it, it seemed desirable to ascertain whether the simple addition of a salt of iron, with lime sufficient to neutralize the acid of the salt, would produce results similar to those attained by Webster's process.

"In order to make these experiments, samples of fresh raw sewage were taken at Crossness at intervals of one hour during the day. As much as 10 grains of different salts of iron were added per gallon, plus 15·7 grains of lime in some cases, and 125 grains of lime in another, and the treated sewage was allowed to settle twenty-four hours ; the results obtained were not nearly as good as by the electrical method.

"The result of my examination of this process has been to convince me of its efficiency in clarifying sewage, of removing smell, and in preventing putrefaction of the effluent. I am of opinion that such an effluent as I saw at Crossness can be discharged into a river, or, after passing through a thin layer of sand, even into a stream, without causing any nuisance."

Webster's electrical process seems to prove that by its means sewage is effectually purified, clarified, the smell removed, and secondary putrefaction prevented, the bulk of sludge being reduced to a minimum.

The necessary plant consists of electrolytic channels containing the iron plates, the copper conductors and measuring instruments, dynamos, engines, and boilers. Thirty effective horse-power should be provided for treating one million gallons of sewage in twenty-four hours (representing a town of 30,000 inhabitants), assuming that about 450 tons of iron are laid down. This is estimated as ten years' supply, the iron consumed having been ascertained to be about forty-five tons per million gallons per annum. But as the amount of iron laid down is in inverse proportion to the horse-power required, these two factors can be varied to suit the special requirements of each case. It should, however, be borne in mind that the larger the quantity of iron laid down the longer it will last, and the cheaper it will be in the long run.

For one million gallons of sewage in twenty-four hours the cost of the above plant (not including iron) would be about £2,000 ; this would allow for three engines and dynamos (direct driving), and two boilers, any two engines and dynamos, and one boiler, being capable of doing the full load. For dealing with larger quantities of sewage the cost of plant is proportionately less ; for instance, for 10 million gallons the cost of electrolytic channels, dynamos, engines, and boilers would be about £10,000. With modern machinery the coal consumption may be taken as not exceeding 2 lbs. per indicated horse-power. The annual cost of maintenance would comprise only coal, iron consumed, and labour. Two shifts of two men each would suffice for one million gallons. To this must be added interest on capital and depreciation of machinery. For 10 million gallons the coal and iron consumed would be in proportion to the amount of sewage treated, but the labour required would but little exceed that for one million gallons, two shifts of three men each being sufficient.

VII. **Bacteriolysis.**—The results of experience with all the systems that have so far been cited and put to practical proof are unsatisfactory, so much so, that attempts are being made in a great variety of ways to discover and elaborate better methods for the disposal of sewage.

Irrigation farms often create a nuisance at some time or other, and there is an absence of the power of control in their use, as the sewage must be got rid of, so it has to be applied to the land, whether such application at the time is likely to prove beneficial or not, either to the crops or for the purification of the sewage itself.

Should the land become water-logged during heavy rains, or during a severe frost, the crude sewage runs over the surface without any beneficial effect on it, and the effluent is then discharged practically unchanged.

If, on the other hand, the land is porous enough, or sufficiently well drained to prevent its becoming water-logged under other circumstances, the effluent will run through too freely to admit of its proper purification during dry weather.

The acreage as recommended by the Rivers Pollution Commissioners is on the basis of one acre for every 150 of the population. This shows the magnitude of the task involved in applying irrigation on a large scale, for London would require at this rate an area of sixty square miles laid out as an irrigation farm.

Chemical methods of precipitation have also more or less failed, for as soon as the effluent becomes sufficiently diluted with pure water putrefaction sets in.

In all these systems there is the sludge to be disposed of, the methods for doing which are described in Chapter XV.

Mr. Dibdin is of opinion that the whole of the work required to be done in connection with the treatment of sewage may eventually be effected by bacterial agency quite independently of any chemical process, and that chemistry will only be required to gauge the rate and progress of the work.

At an early stage in this important inquiry the fact that there are certain micro-organisms which have a destructive action on sewage and other impurities was recognized, but the principles were but little understood, and it is due to the failures above alluded to that extensive experiments have during the last few years been made in order to discover the nature and extent of their action, and whether it was possible to solve the problem by their aid.

Massachusetts Experiments.—Amongst others the *Massachusetts State Board of Health* during the years 1889–90 made some very valuable experiments at their experimental station at Lawrence, to ascertain whether sewage could be disposed of on biological lines, and have continued them annually since to date.

The following paper, read at a Sessional Meeting of the Sanitary Institute, December 11th, 1895, on the subject of the lessons to be learnt from the experimental investigations by the State Board of Health of Massachusetts upon the purification of sewage, is inserted by the kind permission of the author, Captain Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S., late R.E., Hon. M.Inst. C.E., F. San. I.:—

I have been requested to open a discussion upon some of the general conclusions which may be drawn from the Massachusetts experiments. These have been published for some time, and they have been elaborated by further efforts of engineers both in this country and in America.

My task is to endeavour to give you a brief account of the various experiments which have been made, and to present to you the conclusions to which these various experiments point. My remarks are only intended to open out what we hope may be a valuable discussion on this important subject.

It has practically only been in comparatively recent times that the growth of our population has compelled the public to recognize the necessity for the disinfection, purification, or destruction of refuse matter.

A sparse population could afford to allow the refuse to purify itself gradually in the soil, or in ditches, streams, and rivers ; but as the population and proximity of habitations increase, careful attention must be given to methods of dealing with the refuse to prevent the injurious effects which arise from decaying organic matter in the neighbourhood of dwellings, or from the use of polluted water in our streams and wells.

As a result of the epidemics of cholera between 1830 and 1850, the removal of excreta by water carriage obtained a great development, and during the discussions which took place upon the problem of Metropolitan Drainage before 1858, the utilization of sewage and its purification by application to land received much consideration. The problem was in the hands of the engineer and the chemist, and the conclusions at which experts in sewage then arrived may be generally summed up as follows :—

1st. The direct application of sewage to land is thoroughly effective as a means of purification. There is no sanitary objection whatever to the system of sewage disposal by agricultural irrigation, and no nuisance or offence can arise in connection with it, save as a result of gross neglect or mismanagement. But it entails difficulties in thickly settled districts, owing to the extent of land required.

2nd. The chemical treatment of sewage produces an effluent harmless only after having been passed over land, or if turned into a large and rapid stream or into a tidal estuary, and it leaves behind a large amount of sludge to be dealt with.

3rd. Hence it was long contended that the simplest plan in favourable localities was to turn the sewage into the sea, and that the consequent loss to the land of the manurial value in the sewage would be recouped by the increase in fish life.

Purification was originally supposed to be due to the oxidizing effect of the air, but the researches of Schloessing, in France, and Frankland and Warrington, in England, brought the biological element into consideration.

Schloessing found that when sewage was passed through baked sand and marbles no purification was produced at first, but that later the effluent became clear and free from organic matter. He found that this purification was arrested by the presence of chloroform in the sand, and that it began again when the chloroform was washed out. This confirmed him in the conclusion that purification requires the co-operation of living organisms.

Warrington believed that nitrification was due to living organisms chiefly confined to the surface soil. And Frankland concluded that purification is a process of oxidation, producing carbonic acid and nitric acid, and that a continual aëration of the soil is necessary.

The conclusion was thus reached that in the direct application of sewage to land, the loam on the surface at once supplies nitrifying organisms ready to convert the sewage into a form suited for food for the plants which are on the land.

Dr. Frankland, many years ago, suggested the intermittent filtration of sewage through a thickness of five or six feet of material ; and Mr. Bailey Denton and Mr. Baldwin Latham were among the earlier engineers who adopted the method.

The simplest theory of the working of any filter is that its action is mechanical, indeed the word " filter " has come to mean ordinarily a more or less perfect strainer. In this aspect the working of the filter is continuous, but it soon chokes and must be cleaned.

The intermittent filter on the other hand presents quite different conditions. It is no longer a mere mechanical strainer. No doubt when first established there may be a period at the outset when it affects little more than a mechanical purification ; but, under the best conditions, there speedily begins a change of the profoundest significance. The filter becomes a method of developing the conditions which favour the action of bacteria by the exposure of the sewage in the presence of air.

The Massachusetts experiments may be said to have taken up the question at this point. The experiments show that a sand filter does not affect the nitrification when first used. Time is necessary for it to accumulate a suitable colony of bacteria. Furthermore, the colony adjusts itself to the work it has to do. If, then, the amount of sewage is suddenly increased, and is continued at the larger amount, the nitrification will at first be incomplete, but the bacteria will soon multiply and purification will again become satisfactory, often amounting to the destruction of 99½ per cent. of the nitrogenous matters in the sewage, and all but a fraction of 1 per cent. of the bacteria.

Nitrification is affected by the season and by temperature. It is most active in the growing months of May and June—even more so than in the hotter months of July and August. With this exception the amount of nitrification varies with the amount of the sum of the ammonias in the sewage, so that, in the winter months of 1888–89, while the nitrates of the effluent were lower than at other times, it was found that the sum of the ammonias in the sewage was also lower, and *that nitrification at that time was quite as complete as in the previous months.*

The general conclusions were thus summed up in the report of the chemist to the experiments, Mr. Hazen :—

" The purification of sewage by intermittent filtration depends upon oxygen and time ; all other conditions are secondary. Temperature has only a minor influence ; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use.

Imperfect purification, for any considerable period, can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through, that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand particles, in contact with an excess of air, for a sufficient time, is sure to give a well-oxidized effluent; and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. *It must hold both air and sewage in sufficient amounts.*"

As the object of this paper is simply to produce a discussion upon this interesting subject, I will not enter into those further details which are fully supplied in the report. But I will proceed to draw attention to certain methods which have been proposed by engineers, both in this country and in America, with the object of facilitating and regulating the aëration of filters. Mr. Lowcock in 1893 read a paper before the Institution of Civil Engineers in which he summarized the Massachusetts experiments, and showed the result of some further experiments of his own, in order "to ascertain the possibility of constructing and working a filter that should follow the operations of nature, and promote the growth of the nitrifying organisms and the consequent purification of a sewage effluent, when working continuously."

Mr. Lowcock's method was to supply air continuously under pressure into the body of the filter, so as to afford to the bacteria the necessary means of subsistence.

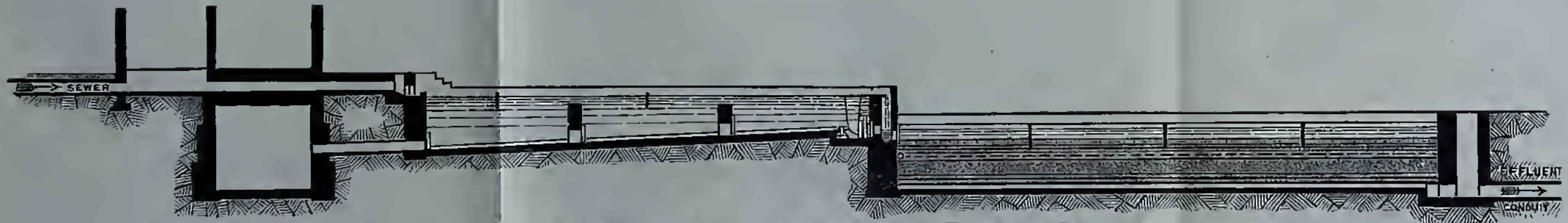
I annex a plan and two sections of Mr. Lowcock's filter (Plate XLI. and Fig. 514).

TABLE 84.

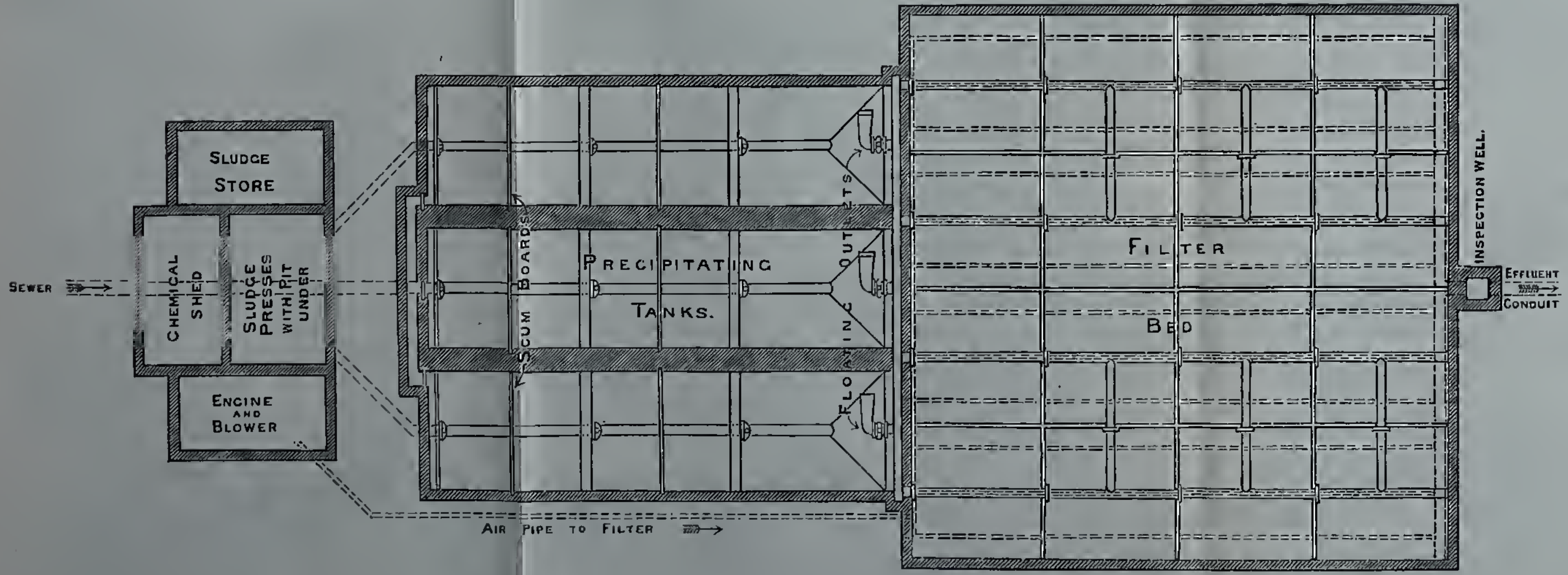
	Parts per 100,000.	
	Crude Sewage.	Effluent from Filter.
Free ammonia	4·65	·04
Albuminoid ammonia	2·40	·036
Total	7·05	·076
	Sewage after Precipitation in Tanks.	Effluent from Filter.
Free ammonia	6·40	·008
Albuminoid ammonia	·70	·022
Total	7·10	·030

LOWCOCK'S PATENT FILTER.

Arrangement of Precipitation Tanks and Filter for the Treatment of 100,000 Gallons of Sewage per Day.



Longitudinal Section through Sludge Tank, Precipitating Tanks, and Filter Bed.



Scale 20 feet to an Inch.

To face page 478.

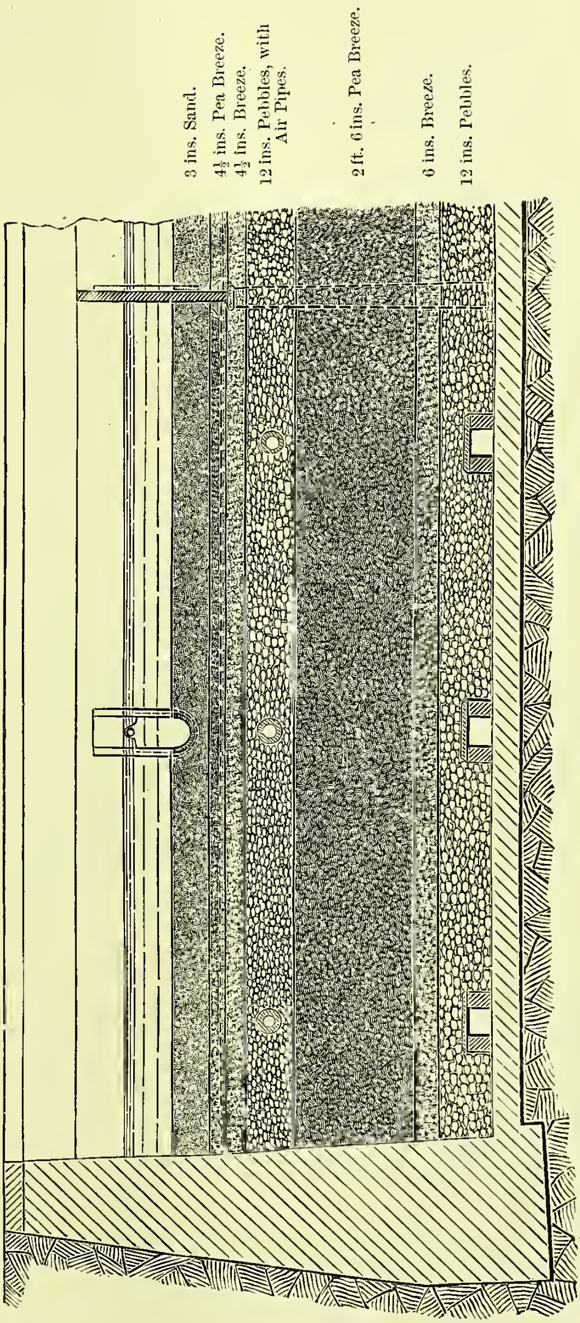


Fig. 514.—Section of One Division of Filter Bed of Lowcock's Filter. Scale ¼-inch to a foot.

Mr. Lowcock points out that "the practical difficulty with all filtration is the clogging of the surface, whilst this affects the quantity passed in an inverse ratio it also affects the degree of purification directly; that is to say, the greater the clogging of the surface, the more slowly does the liquid pass through the filter and the greater the consequent purification. It would appear, however, from the comparison of the experiments, that this clogging does not take place so quickly when air is being supplied to the body of the filter as when it is not; and this is probably due to the matters which produce the clogging being

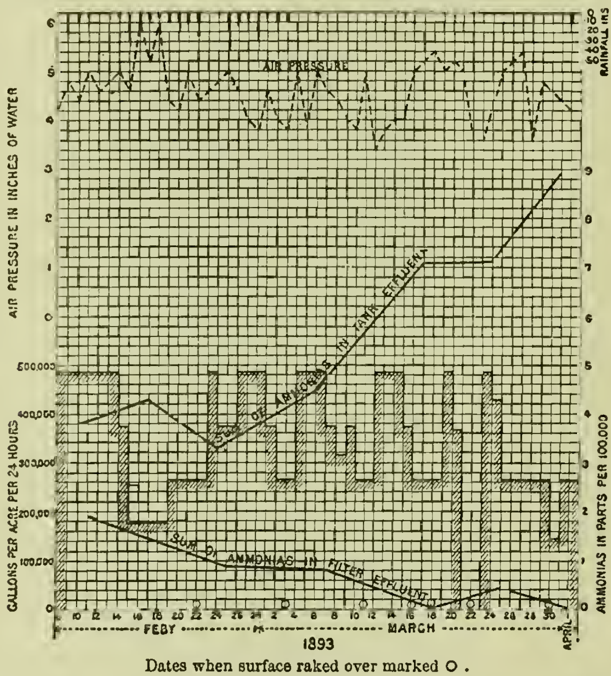


Fig. 515.—Diagram showing Result of Mr. Lowcock's Experiments.

broken up and destroyed in the presence of the air directly they pass below the surface."

Mr. Lowcock's experiments coincide with the conclusions arrived at in the Massachusetts experiments, that the filter does not reach its condition of greatest efficiency for some little time after it is started, and that the efficiency is impaired by variations in the quantity of liquid applied.

The above Diagram (Fig. 515), which is reproduced by permission from a paper read before the Institution of Civil Engineers, shows the general result obtained in the experiments.

The average quantity applied during the period covered by the

Diagram is equal to 353,800 gallons per acre per day, the average air-pressure being 4·5 inches of water. The quantity applied when the most satisfactory results were obtained was at the rate of 263,780 gallons per acre per day ; so that at this rate the area required per million gallons of effluent of the same impurity as that experimented with, would be 3·8 acres. The dry weather flow of the sewage experimented upon is 16 gallons per day per head of the population, so that the quantity treated at the most efficient rate is equal to that from 16,486 persons per acre.

In his later development for treating the Wolverhampton sewage, Mr. Lowcock has substituted coke breeze for gravel in the body of the filter, and improved the arrangement for distributing sewage over the surface of the filter. The following Table summarizes Mr. Lowcock's results in October, 1895 :—

TABLE 85.—ANALYSIS OF THE EFFLUENT FROM THE SETTLING TANK AS APPLIED TO FILTER, AND THE RESULTING EFFLUENT FROM FILTER IN PARTS PER 100,000.

October 8th, 1895.	Tank Effluent applied to Filter.	Effluent from Filter.	Percentage of Reduction.
Free ammonia	4·00	1·20	70
Albuminoid ammonia	0·35	0·07	80
Oxygen consumed	1·70	0·40	77
Nitrogen as nitrites and nitrates	traces.	2·68	
Chlorine, grains per gallon	14·00	16·80	

The percentages of reduction are calculated on the tank effluent ; if calculated on the sewage, the results of the whole treatment, tank and filter, would be a reduction of considerably over 90 per cent.

The Wolverhampton sewage is a most difficult one to deal with, as it contains a large quantity of manufacturers' and acid waste.

As regards the refuse from dye-works and woollen factories, Mr. Lowcock states that his experiments appear to show that when the refuse is properly treated in tanks first, and the resultant tank effluent is slightly alkaline, there is no prejudicial effect on the filters or on the quality of the effluent ; and in the treatment of refuse from dye-works the organic colouring matter is removed by the filter at the same time as the albuminoid ammonia.

Mr. Scott-Moncrieff has also proposed a cultivation filter bed, which would seem to have been designed chiefly for institutions or large residences.

"The filter bed is about 3 feet deep and 2½ feet wide, and 10 feet in length. The entire sewage discharge and waste waters from a household of from ten to twelve persons (with the exception of the grease, which is held back as far as possible by a grease trap) finds its way into one end of this filter bed. The liquid portion rises through a false bottom, and then through successive layers of flint, coke, and gravel, till it reaches the level of the overflow pipe, which is about two inches below the level of the invert of the drain. The depth of the filtering medium is only about fourteen inches. The cubic capacity of the filter bed is thus so small that the natural expectation would be that in a few days the filtering medium would become choked, and a nuisance result. As a matter of fact, however, the reverse of this happens, the effluent up to a certain point actually improving in quality as time goes on, and the whole process continuing to work satisfactorily and uninterruptedly for months together without constituting a nuisance."

The filter beds and channels are in duplicate to allow of periodical aëration.

My friend, Col. George Waring, the well-known sewage engineer in America, has pursued the same line of investigation upon a practical scale with a somewhat different arrangement from Mr. Lowcock's. He obtained permission in 1894 to treat a portion of the sewage of Newport, Rhode Island. The sewage was taken from "the main outlet sewer. . . . The sewer at this point is five feet wide and five feet deep, and with a grade of 1 to 2,000. At the end of the wharf, 104 feet beyond the point selected, the sewer delivers into a large settling chamber, and from this an iron pipe, laid on the bottom of the inner harbour, leads beyond the breakwater and discharges into the main channel. A storm overflow in the settling chamber . . . allows the direct discharge of sewage into the inner harbour at times when the flow is unusually large. This overflow is provided with low tide gates, but very high tides sweep over these and flood the settling chamber with salt water. The city is sewered according to the combined system. The street inlets deliver into large catch-basins, which in dry weather are little better than cesspools. Many of the sewer connections are merely overflows from the cesspools, receiving only liquid which is stale and putrid.

"Th main sewer, which of necessity has very little fall, is a sewer of deposit, in which putrefaction is constantly going on. Because of these conditions, the sewage used in the experiments was often far from 'fresh,' although the analysis showed it to be of normal composition and fair average strength. It contained practically no manufacturing wastes, although at times there was evidence of the presence of gas liquor. The sewage was raised by means of a 10-inch diaphragm pump, which was placed with a 3-inch galvanized iron suction running to within about 3½ inches of the bottom of the sewer.

"The mouth of this suction was open full bore, so that a fair sample of the sewage, solids as well as liquids, might be had. . . . The capacity of the pump at full stroke was ·81 gallons, but its average throw during the experiment was about ·28 gallons, and its average speed was five to eight strokes per minute. . . . A chemical laboratory was provided, suitably equipped for the determination of free and albuminoid ammonias, consumed oxygen, dissolved oxygen, chlorine, etc., and for the recording of meteorological conditions. The . . . pump delivered the flow . . . at will to either side of a partition which divided into two sections (for alternate use) a shallow bed of coarse broken stone. . . . The function of this bed was to catch and retain the coarser solids contained in the sewage, before passing it to the tanks below." When one section was choked the flow was turned into the other. "The impurities in the section thrown out of use disappeared rapidly in its interval of rest."

The function of the straining tanks was mere mechanical sedimentation. Each tank had a diameter of about six feet at bottom; the outer sides slightly tapering inwards, and a depth of about five feet six inches, of which five feet was filled with the filtering material. See Figs. 516, 517*, and Plate XLI., page 478, and Plate XLII., page 486.

"From the straining apron, the sewage, freed from its coarser solids, passed to the straining tanks. Of these there were originally four similar in construction, but filled with different materials. Each tank has a total capacity of about 985 gallons. The top of No. 1 was about four inches below the delivery of the straining apron, and each succeeding tank was six inches lower than the one next before it, so that the tanks could be used in series if desired, the overflow of No. 1 delivering into No. 2, the overflow from No. 2 in turn passing to No. 3, and so on. The internal arrangement of one of these tanks is shown in Fig. 519. *A* is a false bottom of plank, perforated with $\frac{3}{4}$-inch holes about four inches apart, and supported a few inches from the bottom on cleats. *B* is a galvanized iron air-pipe, six inches in diameter, branching from a 12-inch air main, and delivering through the false bottom into the open space below. *C* is a layer of coarse broken stone (1 to $2\frac{1}{2}$ inches) six inches thick. . . . *D* is a cylindrical diaphragm, of hooped staves, resting upon the broken stone, *C*, and dividing the surface of the tank into a circle and a ring of equal area. *E* is the material with which the main body of the tank, inside and outside of the diaphragm, was filled. In tank No. 2 it was fine broken stone ($\frac{3}{8}$ to $\frac{3}{4}$ inch); in No. 3, round pebbles, of diameter ranging from $\frac{3}{8}$ to $\frac{5}{8}$ inch; and No. 4, coarse white gravel, of very uniform size, free from sand, each grain being about $\frac{1}{8}$ inch in diameter. Each of these tanks was fitted with a drainage cock, *F*, near its bottom, and a hole bored through the bottom

* Figs. 516 and 517 will be found on folding sheet facing page 484.

and closed with a wooden plug, *G*, provided means for the rapid and complete emptying of any tank when desired for the purposes of cleansing.

"A smaller cock, *H*, was placed near the top of each tank, just below the overflow line, and from this samples were taken for analysis and examination. The partially strained sewage from the apron was delivered on the surface of one of these tanks in the circle enclosed by the diaphragm. It passed down through the central cylinder of filtering material and under the diaphragm, and rose again through the annular space outside of the diaphragm overflowing through a spout into a gutter. This gutter led the liquid either to the central circle of the next straining tank, when two or more of these tanks were used in series, or to the aërating tank, for further treatment."

As has been stated, the function of these four "strainers" was mere mechanical sedimentation. The liquid flowed slowly through them and the suspended matters, which were more or less fibrous or gelatinous in their nature, became attached to the particles of the filter, the coarser of them being deposited near the surface of the central cylinder, and the finer progressing further and further into the mass. It was found that practically all of the solid matters were deposited in the central core during the downward flow of the water, and that very little work remained to be done as the liquid rose in the outside ring. This was the case when the sewage was applied at the maximum rate attained in the experiment, 8,950,194 gallons per acre, the water moving through the tank at the rate of about three feet per hour.

As a rule, sewage was passed through a strainer until the resistance from the collection of matter was so great that the liquid in the inner compartment overflowed the diaphragm. The rate at which this clogging matter gathered was very variable. It was noticed that an admixture of salt water materially increased it, evidently from precipitation of soap; and that putrefaction, as has been indicated, tended to decrease it by making soluble compounds.

The suspended matter or sludge thus removed from the sewage, mechanically, by the strainers was afterwards destroyed by emptying the strainer through the plug, *G*. The liquid was drawn slowly through the cock, to prevent such disturbance of the sediment deposited upon the particles of the stone as a rapid flow would have caused. Air was then forced through the filter so as to induce bacterial action. By this means the cleansing was easily effected.

The effluent from the strainers was led to a distributing box, from which it escaped over a level weir, the flow being divided by movable knife-edge gates, which regulated the amounts applied to the aërators.

SECTIONS OF STRAINING TANKS. (Waring's Filter.)

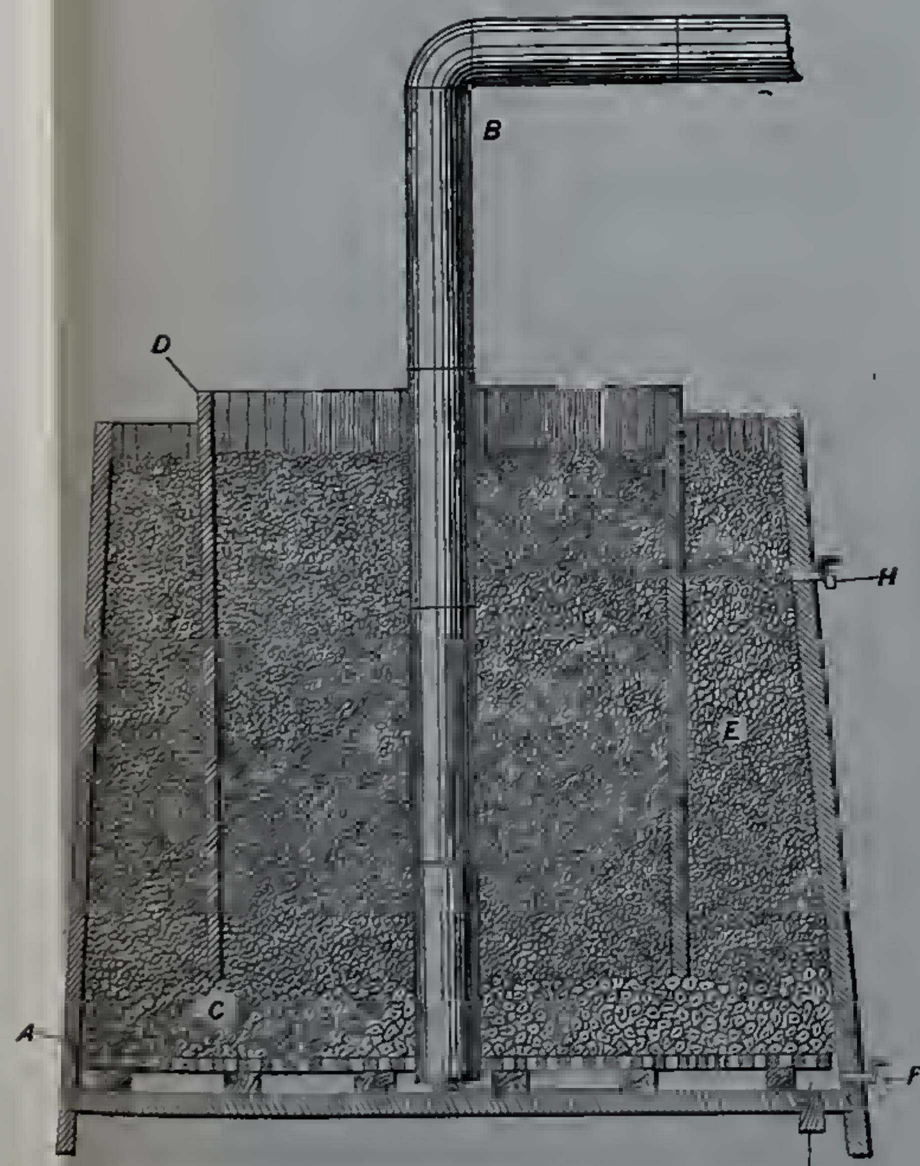


Fig. 516.

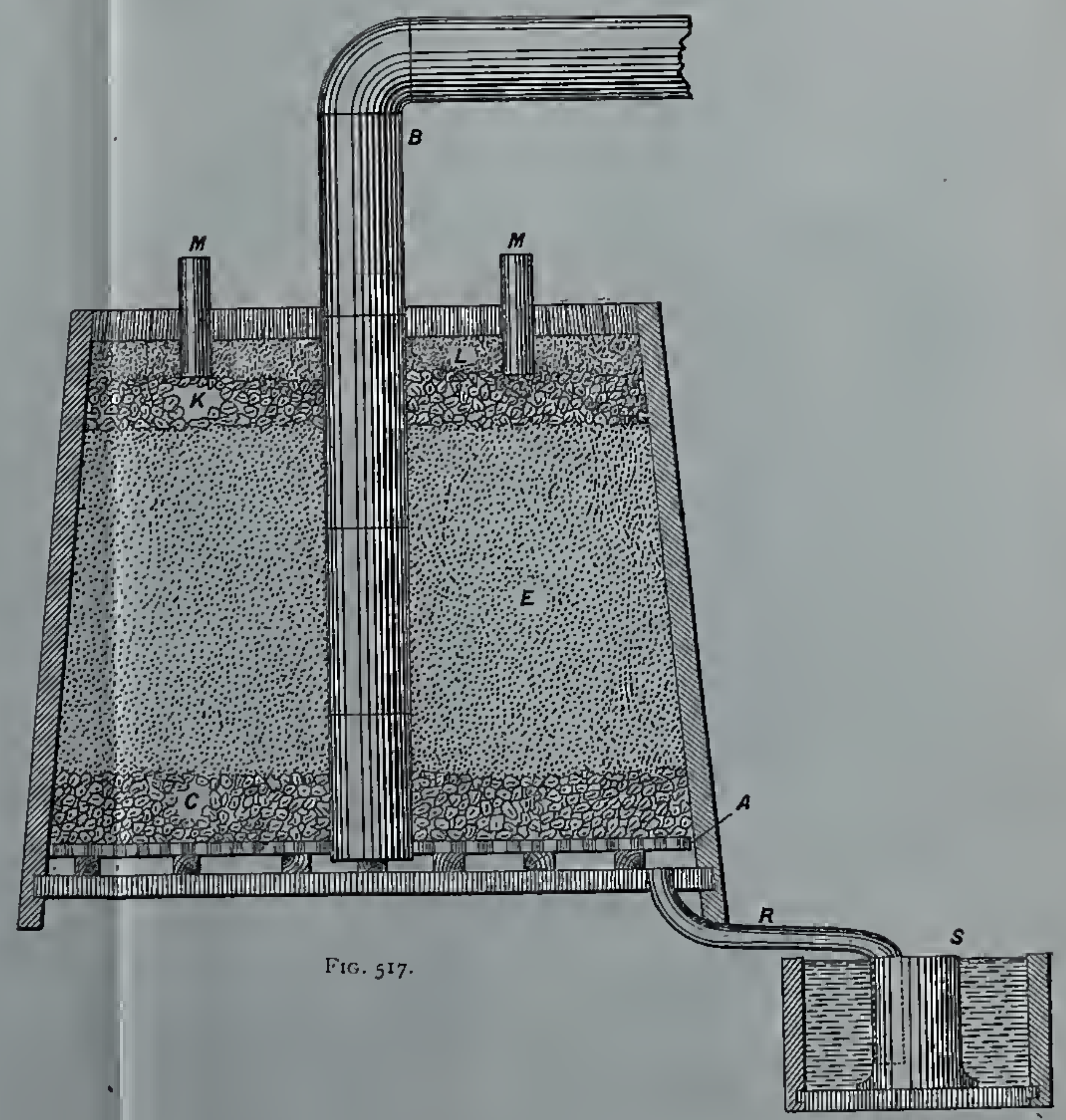


Fig. 517.

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The aërating tank is shown in Fig. 517. "This tank was of the same size as the others, and was set six inches lower than the strainer. It had a perforated false bottom, with an 8-inch air-pipe delivering into the space below it. On this bottom was placed six inches of coarse broken stone, *C*, which was packed at the top with smaller stone, so as to support firmly the finer filling material, which was clean white gravel, *E*, each grain being about ⅛ inch in diameter . . . and three feet nine inches deep. On this was placed another six inches of coarse broken stone, *K*, packed with finer stone at the top, and the whole was covered with six inches of fine beach sand, *L*. Two vent pipes, *MM*, made of single lengths of round 4-inch agricultural tile, pierced the covering of sand, and communicated with the upper layer of broken stone beneath it. This tank had no diaphragm. The effluent from the strainers entered at its top, trickled down over the broken stone and gravel, and ran out at the bottom through the pipe, *R*, which discharged into an upright length of vitrified pipe, *S*, closed at one end, effectually trapping the outlet, and preventing air from escaping with the effluent. This trap overflowed into a rectangular wooden tank of about 350 gallons capacity, sunk in the ground, which collected the effluent and allowed convenient inspection of it in bulk."

In the aërating tank the forced aëration was constant. Air was delivered at its bottom, and rose through the gravel to the upper layer of broken stone, and thence escaped, by means of the vent pipes, to the outer air.

The liquid which was constantly trickling down in thin films over the surfaces of the broken stone and gravel was always in immediate contact with a current of fresh air passing in an opposite direction through the voids between the particles of stone.

When the sewage was first applied, it sank through the layer of sand within a few inches of the point at which it was delivered, and passed quickly through the tank, showing little or no improvement as it escaped. Gradually, however, the surface of the sand became partially clogged and the sewage was distributed over a wider area, until at length the whole surface of the tank was covered with liquid two or three inches deep. This secured uniformity of distribution throughout the tank. Gradually, also, the organisms of nitrification began to multiply and to seize upon the dissolved impurities, destroying their organic character and transforming them into nitrites and nitrates, in which unobjectionable mineral form they escaped with the effluent. The first signs of this action were shown on June 12th. Once started it increased rapidly, and by June 27th the average working rate of nitrification was reached. From this time to the end of the experiment the operation of this tank was practically constant, occasionally influenced by changed conditions, as is shown in the Tables of analyses, but quickly adjusting itself to these conditions.

In a strainer, during its periods of use, the voids of the material were completely filled by the flow of sewage. In an aërator the voids were mainly filled by a constantly moving current of air, the liquid passing down, not in bulk, but in thin films, which worked their way over the surfaces of the particles of gravel or coke. The capacity of an aërator was, therefore, much less than that of a strainer of the same size.

The general arrangement with the straining apron, a group of four straining tanks, and one aërating tank, is shown in Plate XLII.

The average daily flow through the strainer was at the rate of 3,787,300 gallons per acre ; the maximum was 8,950,194 gallons ; and through the aërators at the rate of 1,064,213 gallons, the maximum, after nitrification began, being 4,826,112 gallons.

The Table, page 489, shows that the average percentage of purification, as represented by the removal of organic nitrogenous matter, accomplished by the strainers alone, was 51·2 ; and by the strainers and aërators together, 92·5. At one time a purification of 99·08 per cent. was reached.

The sole function of the forced aëration was to supply oxygen to the interior of the tanks in sufficient quantity to excite and maintain the maximum activity of the bacteria of decomposition ; although the presence of oxygen is necessary for constant purification, no benefit is derived from the supply of an excess. Towards the close of the experiment, the air-pipe was closed and a ⅜-inch hole opened, reducing the supply, theoretically, by three-fourths. The tank was operated with this amount of air until the close of the experiment. The effluent showed no signs of deterioration, and the supply appeared to be ample.

Colonel Waring observes that probably a vigorous aërating of the filter for, say five minutes in each hour, thoroughly changing the air in all its voids, would store sufficient oxygen to keep the bacteria active until the next period of aëration. This course would probably be wiser than an attempt to furnish a constant supply at a lower pressure, for, in the latter case, the more remote or compact portions of the filter might not be penetrated by it ; while intermittent aëration at a higher pressure would force the air into every crack or corner, and secure the efficient operation of all parts of the mass. By means of light partition walls or diaphragms the filtering material could be divided into sections, which could be aërated vigorously in turn. Assuming that the above suggestion of five minutes' aëration in each hour should prove practical, the entire filter could thus be satisfactorily operated with one-twelfth

VIEW OF STRAINING AND AËRATING TANKS. (WARING'S PATENT FILTER.)

To face page 486.

of the air and power which would be used if the aëration were constant.

When the station was dismantled and the tanks taken apart after the experiments, the upper foot (approximately) of the central compartment of each of the straining tanks showed more or less accumulation of silt, probably the result of the few heavy rainfalls during which pumping was continued bringing much gutter mud to the tanks. Below this, the material was apparently as clean as when first put in, the pebbles and white gravel looking as though they had just been taken from their native beach. In no part of the tanks was there any sign of organic matter or any suggestion of the hundreds of thousands of gallons of sewage which had been passed through them. The thin layers of sand on top of the aërators were black with sulphide, but all the material below this was sweet and clean. No impurities had been *stored* in any of the tanks. They had been detained and destroyed. All the conditions clearly indicated that the usefulness of the filters had become in no wise impaired, that they were capable of performing their functions indefinitely, and that, under proper management, no renewal of the filtering medium would be necessary.

The following is a summary of the conclusions to which these various experiments lead us, viz. :—

1. The suspended matters of sewers (sludge) can be mechanically withheld by straining slowly through suitable material.

2. The filth accumulated by this straining material can be destroyed, and the straining medium restored to a clean condition by mere aëration.

3. The successive alternate operations of fouling and cleansing can be carried on indefinitely without renewal of the straining material.

4. The purification obtained by this straining process practically equals that accomplished by chemical precipitation, and is sufficient to admit of discharge into any considerable body of water not used as a source of domestic supply, or for manufacturing purposes requiring great purity.

5. Such filters can be maintained in *constant* and *efficient* operation by suitable aëration.

6. The erection of a plant capable of purifying large volumes of sewage upon a relatively small area calls for no costly construction. Repairs and renewals are merely nominal. The attendance required is but slight. There is no outlay for chemicals, etc. The only expense of mechanical operation is the driving of the blower or air-compressor.

The process admits of wide variation in the selection of filtering material, and nearly every community can find, in its local resources, something suitable for the purpose.

Summary of results obtained by Colonel G. E. Waring, Junr., M.Inst.C.E., at Newport, Rhode Island, U.S.A.

All the figures are corrected for loss due to draining the straining tanks before aëration.

The percentage of purification is estimated from ammonia figures, and respresents—

1. In column marked A the percentage of nitrogen removed from the *sewage* after passing through the straining tank.
2. In column marked B the further percentage of nitrogen removed from the *effluent* after passing through the aërating tank.

The first, therefore, is a measure of the purification of the original sewage on leaving the straining tank. The second set of percentages is a measure of the further purification of the effluent by the aërating tank.

Tank No. 1 Strainer.

Filtering surface $\frac{1}{1980}$ of an acre. Filled with coarse broken stone. Voids of stones after drainage = 43 per cent. Capacity for sewage 450 gallons, being allowance for drainage.

Tank No. 2 Strainer.

Filled with fine crushed stone. Filtering surface $\frac{1}{1980}$ of an acre. Capacity for sewage 450 gallons, being allowance for drainage. Voids of stones after draining = 44·1 per cent.

Tank No. 3 Strainer.

Filled with coarse beach gravel. Filtering material surface $\frac{1}{1980}$ of an acre. Capacity for sewage 350 gallons, being allowance for drainage. Voids of gravel after draining = 32·1 per cent.

Tank No. 4 Strainer.

Filled with fine beach gravel. Filtering surface $\frac{1}{1980}$ of an acre. Capacity for sewage 350 gallons, being allowance for draining. Voids of gravel after draining = 34·4 per cent.

Tank No. 5 Aërator.

Filled with fine beach gravel. Filtering surface $\frac{1}{1920}$ of an acre. Voids of gravel after draining = 34·4 per cent.

Tank No. 1 Aërator.

Filled with coke (screening half). Filtering surface $\frac{1}{1910}$ of an acre. Voids of coke = 38·9 per cent.

TABLE 86.

Tank.	Total Days Pumping.	Total Gallons Pumped.	Average per cent. of time Pumping.	Average Air Pressure inches of Water.	Total Gallons per Acre.	Daily Average Rate.	Total Days Aëration.	Average of Purification.	
								A	B
			Aver.	Aver.					
1	26	54,449·5	77·2	$1\frac{5}{8}$	107,810·000	4,147·000	37	49·2	49·2
2	71	129,039·7	63·2	$1\frac{1}{2}$	255,599·000	3,045·000	69	46·3	38·5
3	88	159,345·5	75·1	$1\frac{1}{2}$	315,543·000	3,584·000	61	53·0	36·8
4	71	130,817·7	77·1	$1\frac{3}{4}$	258,917·000	3.646·000	78	56·2	24·5
5	138	76,110·7	71·1	$2\frac{1}{8}$	146,178·000	1,060·000	148	90·3	77·2
1	67	34,097·8	78·2	$2\frac{1}{2}$	65,124·000	972·000	65	94·7	90·8

Discussion.—Prof. W. H. CORFIELD (London) regarded the experiments made by the Massachusetts Board of Health as very largely confirmatory of our English experiments in the filtration of sewage and its application to land. The experiments of Frankland and the practical results obtained by Bailey-Denton and Baldwin Latham taught that the use of sand and gravel was quite effective as a filtering medium for sewage if properly applied. The experiments made in sewage filtration and published by the Sewage Committee of the British Association showed that filtration was as effective in winter as in summer. The Massachusetts experiments were valuable chiefly as affording confirmatory proof of our previous experience. The experiments referred to in Sir Douglas Galton's paper further evidenced the fact that filtration was even in winter far more effective than chemical precipitation, and also that acid sewage could be treated if a layer of limestone were placed in the upper part of the filtering media. In water filtration it was shown that the results were more satisfactory if the scum which gradually formed on the top of the filter was allowed to remain, but the Massachusetts experiments showed that the scum formed by sewage on land should be systematically broken up. Here no new fact was brought to light, for it was well known to the sewage farmer that the results of ground enriched by sewage manure were better if the surface of the land treated was broken up.

Mr. S. R. LOWCOCK (Birmingham) agreed that the principles on which the Massachusetts experiments were based were perfectly well known in this country, and what they had done was to demonstrate practically that these principles were correct, and they were therefore most valuable. The theory of sewage treatment, whether on land or by means of special filters, is exactly the same, and the failures in sewage purification which not infrequently occur are due to neglect of the principles on which this theory is based. The error of those people who say that the engineer of to-day knows nothing (or very little) about sewage treatment is due to the fact that such persons know nothing of the extensive literature of sewage treatment which now exists, and do not read up, or in other ways do not make themselves acquainted with the real facts. He was very pleased to know that in America Col. Waring had obtained similar results to those he himself had obtained in this country, the only practical difference between Col. Waring's system and his own being in the method by which the filtering medium was aërated. If Col. Waring's straining tank were superimposed upon the aërating tank the arrangement would be almost identical with his own, but the aëration would be from the bottom upward to the middle layer, whereas in his own it was downward from the middle layer to the bottom. He quite endorsed the conclusions as to the clearing of the straining material, as he had found that the surface sand removed from his filters and merely turned over in the presence of air, in the course of a very few days became perfectly clean and could be re-used. In comparing the results obtained by various systems, not only as between America and this country, but in different towns and districts in the same country, due consideration must be given to the different characteristics and strengths of the sewage treated, as these differences control the qualities which can be dealt with on any given area, and the measure of purification which can be obtained. His own experiments showed this very clearly; at Malvern Link, where the sewage is of a purely domestic character, he had obtained a purification of over 99 per cent. from the tank effluent to the filtrate, while at Wolverhampton with exactly similar arrangements the purification, calculated on the same basis, so far has only reached 85 per cent. This is entirely due to the character of the sewage, which is quite abnormal and extremely difficult to treat. There are a large number of galvanizing and other works in the district, and in spite of vigilance on the part of the authorities large quantities of acid waste are discharged into the sewers, or, when the waste is treated at the works

TABLE 87.

No.	Tank Effluent.					Filter Effluent					Reduction per Cent.		
	Free Ammonia.	Albuminoid Ammonia.	Nitrates and Nitrites.	Oxygen.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrates and Nitrites.	Oxygen.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Consumed.
1	6·7	·40	Traces	2·5	17·8	4·0	·20	·50	1·5	17·0	40·0	50	40
2	4·0	·70	Traces	3·5	14·0	2·8	·20	·45	1·7	14·0	30·0	71	51
3	6·0	·70	Nil ...	5·3	22·4	1·6	·25	2·40	1·9	21·5	73·0	64	64
4	6·0	·60	Traces	1·9	24·5	1·4	·30	2·56	·6	24·4	75·6	50	68
5	6·6	·60	Traces	1·4	26·7	1·6	·30	2·56	·4	26·6	76·0	50	71
6	4·0	·35	Traces	1·7	14·0	1·2	·07	2·68	·4	16·8	70·0	80	77
	Parts per 100,000.				Grains per Gallon	Parts per 100,000.				Grains per Gallon			

quantities of chloride of calcium are discharged. The result is shown in the preceding Table by the unusually high amount of chlorine.

The Table shows a set of twelve analyses, six of tank effluent, and the corresponding six of filtrate, taken at various periods extending over twelve months, during which time the filter has been continuously at work. These samples are an average of twelve hours' flow in each case. The filter was started in October, 1894, and the first pair of samples were taken a month afterwards, and the others at intervals until the last were taken on October 8th, 1895. The rate of flow was 1,000,000 gallons per acre when samples four and five were taken, and 500,000 gallons when the other samples were taken. The analyses are interesting as showing the effect of the chlorides on the purification, as, although throughout the whole series the results, as judged by the oxygen consumed and the large increase in the nitrates, show continuous improvement; yet where the chlorine is high there appears to have been a retarding action which prevented the breaking down of the albuminoid ammonia, or combined it in some stable form, the nitrification reducing the free ammonia in larger proportions, while when the chlorides are lower the albuminoid ammonia is reduced in larger proportions. The nitrifying organisms are evidently very active, and this is further proved by the fact that none of the samples of filtrate have undergone putrefaction, but have almost uniformly developed a green growth. His own experience agreed with that of the Massachusetts experimenters and Col. Waring, that a very small quantity of air is sufficient, and that nothing is gained by an excess, and that where the aëration is sufficient very complete purification of the sewage is effected, and the filtering media are kept perfectly sweet and clean for apparently an indefinite period.

Mr. Scott-Moncrieff (London) said that when he commenced his experiments the reports of the Massachusetts Board of Health were not made known. As a matter of fact the first biological filter bed ever used in England had been constructed by him at his own house and practically applied in July, 1892, and since then many others had been adopted. His investigations had been carried out upon lines which differed greatly from those referred to in the paper, and he had no doubt but that the subject, in the course of a few years, would be discussed in a way that at present was not possible. The knowledge of the habits and methods of the organisms which carried on the work of putrefaction and purification, outside of the laboratory, was at present of a most meagre kind, the attention of bacteriologists having been almost exclusively devoted to the study of organisms in relation to disease. Referring to the diagrams, he said that in the case of Col. Waring's upward "strainer" no doubt a considerable breaking up of the organic matter occurred, but it was a mistake to suppose that any large provision of air was required for this most important part of the general process. There were reasons for believing that the work of liquefaction was carried on first by aërobic organisms which so completely exhaust the oxygen contained in sewage that it becomes possible for anaërobic organisms, which are equally active, to finish the process. Their combined operations would besides other products yield a large amount of free ammonia, the presence of which in the effluent is always a proof of the activity of the organisms. Again, referring to the diagrams, he said that the downward filters of Col. Waring and Mr. Lowcock with special provision for mechanical aëration would probably be found to be applicable to the final mineralisation of the organic matter by the special organisms of nitrification. Certainly such appliances as had been described did not represent anything approaching to the full process of conversion from the organic to the inorganic state. For instance, any apparatus which provided for the deposition and removal of the organic sludge previous to the bacteriological treatment of sewage, as shown in Mr. Lowcock's diagram, was obviously defective, inasmuch as it deprived the organisms of the food which it was their function to liquefy and mineralise, completing the cycle of nature from the effete products of animals to the nourishment of growing plants. He had no doubt that this process, to which he had given the name of "biolysis," would before long be looked upon, on its practical side, as a most important branch of the science of bacteriology.

Dr. S. Rideal (London) said although the experiments of Col. Waring were new to him, yet they confirmed the results of those already published by the Massachusetts Board of Health, and by Mr. Dibdin, of the London County Council, whose work, judging by the report issued by the Main Drainage Committee in the summer, seemed to be very far ahead of the Massachusetts experiments. The terms "filter" and "filtration," as applied to these methods for purifying sewage, are not happy ones, as these terms are now better restricted, as Dr. Down has himself pointed out, to the removal of bacteria as well as of suspended matter from liquids; and he thought it would be better if the words "strainer" and "aërator" were used in describing such apparatus. Nitrification is a word very often used in connection with these matters, but is often misused so as to be almost equivalent to the term purification. Nitrification is the term given to the conversion of ammonia into nitrous and nitric acids by organisms, and ought not to be applied to the breaking down of the organic nitrogenous matter into ammonia. There were some twenty or thirty organisms known to bring about nitrification, and some or all of these live and move and have their being in the aërators, but they were totally distinct from the organisms which had the effect of breaking down the original matter in the strainer. The initial process might be called hydrolysis, or the resolution of the complex organic compounds into simpler ones, without the addition of oxygen from the air. This breaking down of the solid fæces does not take place readily under ordinary circumstances, owing to the fact that it contains compounds like indole and skatole, which are antiseptic in their action, and which are secreted during the process of digestion in sufficient quantity to bring that process to a standstill. An analysis of fæcal matter shows that it consists of a considerable quantity of undigested food, in addition to cellulose and woody fibres which are not easily digested by man. The natural enzymes of the human system, or adventitious bacteria, would complete this digestion and render a large portion of the solid fæces quickly soluble if the antiseptic compounds were removed. Dilution with water in sewers and cesspools, and still better in these straining tanks, will remove these antiseptics and permit of further digestion. Even cellulose, paper and straw can similarly be rendered soluble by organisms provided no retarding antiseptics are present; and these newer processes of preliminary sewage treatment, as distinguished from precipitation, seem to be capable of explanation on these lines, the final conversion of the ammonia and ammonium compounds into nitrates being effected in the aërators or so-called coke-breeze filters.

Sir A. R. Binnie (Chief Engineer to the London County Council) said that he had been engaged for some years in studying how to dispose of 180,000,000 gallons of crude sewage per day, and that by the method of precipitation adopted 2,000,000 tons of sludge, containing about 200,000 tons of absolutely dry solid matter, are abstracted from this crude sewage and sent to sea every year. There were still, however, three to six grains of solid sewage matter per gallon in the effluent, and he, in conjunction with the Chemist to the Council, had tried experiments with a view to discovering the best mode of removing these, as well as a portion of the dissolved organic matter. In filters of the general description the water stood at two, three, to five feet above the filtering materials, which latter hardly ever got any aëration whatever. They were told that impurities consisted largely of organic matter, and that oxygen was necessary to effectually obviate its harmful effects. Sir Joseph Bazalgette had tried the experiment of oxygenising sewage by atmospheric air, but the effect of it had very little value, and the result of experiments had shown that it was necessary to bring the sewage into contact with the air under peculiar circumstances. As an engineer he had heard of nitrifying organisms, and inquiries of his bacteriological friends elicited the fact that these organisms were of peculiar habit, and could not be cultivated in the ordinary media. The experiments of himself and the Chemist to the Council were directed to finding out the best means of dealing with the effluent of the sewage, and after nine months' work they had come to the conclusion that filtration through coke was the best. The filter was composed of ordinary drain tiles covered with coke, and six inches of sand, the latter not for filtration purposes, but to keep the coke from floating at the top of the tank. The filter was filled and allowed to stand for a few hours, the water being then drawn off. In doing this a vacuum was created, and by atmospheric pressure the whole of the medium was thoroughly and rapidly aërated. The effluent after this treatment was absolutely unimpeachable, being clear and free from smell. But in observing the outlet drains it was at once apparent that the work was not complete. Nature was at work still, and the drains were a beautiful sight, being almost entirely coated with Vorticilla ; yet the Engineer and the Chemist could and did by various processes remove the dead and effete matter, and render the effluent exceedingly pure.

The general result of his experience was that he did not think that any system of filtration, however perfect, would remove and get rid of the 2,000,000 tons of sludge, or the 200,000 tons of dry solid matter ; and although the filters no doubt marvellously improved the effluent from the precipitation channels, yet he feared that even the filters themselves would require to be cleansed, as among the two to six grains of solid matter in suspension in the effluent, there was a certain amount of mineral matter which deposits itself as sticky mud on the upper or sand surface of the filter.

Mr. W. C. Sillar (London) contended that considering the prominence now given to agricultural distress, the utilization of the manurial wealth contained in town sewage should be taken in conjunction with the subject under discussion, which, judging from the terms of the paper read, seemed confined to its destruction merely. It was now no longer a matter of theory but of admitted fact that town sewage can be so treated as to preserve this manurial wealth, and Sir Douglas Galton knows this, as he has himself used it on his farm for several years in succession.

Mr. Dibdin's Experiments.—A large number of experiments on biological lines, in addition to other investigations, have been carried out by Mr. Dibdin, the Chemist to the *London County Council,* during the years 1892–96, the results of which have been published, and have created a widespread interest in this important question.

It was early recognized that the requirements of the micro-organisms must be kept in view in the arrangements made, and that the use of sterilizing agents such as chloride of lime are a mistake, as they destroy the organisms required for the purification of the sewage, and although they remove the offensive odour, yet as soon as the effluent is diluted in the river to a sufficient extent to eliminate the sterilizing action, the sewage begins to putrefy in consequence of the action of the putrefactive organisms in the river-water.

All chemical refuse of an antiseptic nature should then be excluded from the sewers if the sewage is to be purified by the aid of the bacteria.

There are at least two sets of organisms in sewage, the first of which, the aërobic, has received the most attention in connection with the disposal of sewage. They are non-putrefactive, and require a plentiful supply of oxygen to enable them to effect the destruction of the foul matter contained in the liquid, and it has been found that the capacity for work of these microbes depends on the power of the water containing them to absorb oxygen. If this is exceeded in the slightest degree, putrefaction by the anaërobic microbes sets in.

An experimental filter was made, one acre in area and triangular in shape, and filled with coke breeze to a depth of three feet, and then covered with three inches of pebbles on the top, so as to prevent damage from wash. The bottom of the filter bed was provided with a main drain running along an entire side of the bed, with a series of perforated pipes laid herring-bone fashion leading to it. The filter is filled with effluent and then allowed to stand for two hours ; it is then emptied. The whole operation of filling, standing full, and emptying, takes about seven hours, and it is constantly repeated without any intermission for six days ; the filter is then allowed to rest for twenty-four hours. In this way one million gallons of effluent are treated per diem, the purification effected being on an average for the year from 75 to 80 per cent. as estimated by the reduction in albuminoid ammonia, and from 80 to 84 per cent. if calculated from the reduction in the amount of oxygen absorbed from permanganate in four hours.

The filter remains entirely free from putrescent matter, and smells like fresh garden mould, so that it evidently possesses a perfect power of recuperation, and no extraneous aid or renewal is necessary. The only point that has to be attended to is the alternate supply of food and air, so as to maintain the environment and conditions necessary for the proper development and increase of the organisms.

The data so far collected tend to show that it will be possible to increase the depth of the filters, which will be a very great advantage from an economical point of view.

Under this system perfect control is obtainable, as the filters are not affected by climatic and other influences. The effluent is sufficiently pure to pass at once into the river, but if desired it might be utilized to pass over land for the nourishment of crops whenever required. On the other hand, there would be no obligation to so use it when the season or the state of the crops would render its application superfluous or injurious.

When arranging for the disposal of sewage by biological treatment, Mr. Dibdin advocates the removal of the grosser particles by a preliminary screening. The sewage should then be passed through a series of "bacteria beds," consisting of coke breeze or burnt ballast. Half of the beds should be filled with coke breeze of such a size as not to pass a half-inch mesh, thus excluding dust, which would tend to clog the filter. The remaining beds should be filled with the finer description, but with the dust screened out of it.

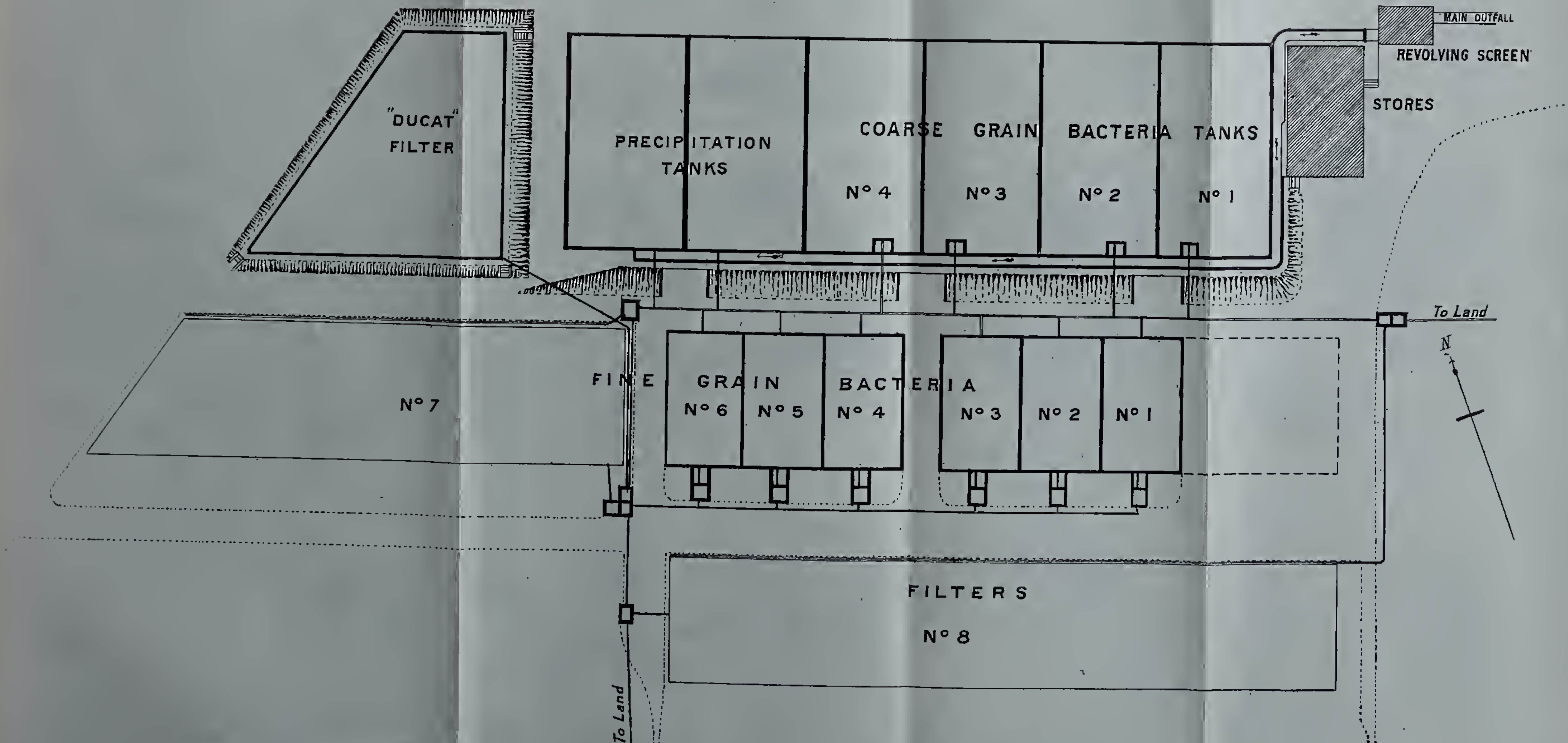
The system of working would be based on the assumption that it takes one hour to fill a bed, two hours being allowed for it to rest full, and one hour again for it to empty ; this would be followed by three hours for it to rest empty. The whole action would thus take eight hours, so that it could be charged three times in twenty-four hours. There might be a series of, say, eight of the coarse grain beds, with one in addition to spare, so that one day's rest in nine may be afforded to each bed, to ensure aëration. The sewage would be run into each in succession, and from each "coarse grain bed" it would be discharged into a corresponding "fine grain bed." If very great purity is required, the effluent might be led into a third series of tanks charged with fine breeze or sand, so that any degree of purity might be attained.

Both at Sutton, Surrey, Hendon, and also at Wolverhampton, filters under biological conditions have been established with most satisfactory results. So far the effluent dealt with has been freed in the ordinary manner from sludge and coarser matters before filtering, but at Exeter it is claimed that the whole of the sludge can be dealt with and destroyed in the same way.

Bacteria Tank at Sutton.—A complete system of sewerage and sewage disposal works was carried out at Sutton in 1893, at a cost of 55,000*l.*, the method adopted being the chemical treatment of the sewage by precipitation and broad irrigation. The quantity of sewage to be treated was estimated to amount to half a million gallons per diem, and flows by gravitation to the disposal works. One-fourth of this volume (viz., the low-level service) has, however, to be pumped at the outfall in order to be passed over the farm or through the artificial filters (Plate XLIIA). The daily dry weather flow of sewage is 400,000 gallons. The population of the district is estimated at 16,000, the population draining to the farm being about 13,000. The sewerage of the district is strictly on the separate system.

The sewage disposal works comprise an area of twenty-eight acres of land—eighteen acres of which only are capable of sewage treatment—

SUTTON (SURREY) SEWAGE DISPOSAL WORKS.



Scale: One Inch = Thirty Feet.

To face page 496

and this area is composed of stiff clay, which is ill-adapted for sewage purification. Complaints as to the ineffectual purification of the sewage led the Council to adopt additional means for the purpose, and eight coke breeze, etc., filters were consequently constructed for the filtration of the sewage after chemical precipitation.

The unsuitability of the soil for the efficient purification of the sewage, and the cost of chemical precipitation and sludge-pressing, compelled the District Council to turn their attention in the direction of other modes of treatment.

When Mr. C. Chambers Smith, C.E., took up his duties in Sutton in October, 1896, the suggestion made by Mr. W. J. Dibdin, F.I.C., F.C.S. (who is a resident of Sutton, and an ex-member of the Council), to try the experiment of treating a portion of the sewage by passing it through a coarse ballast filter, was brought to his notice, and as a result of his experience he advised the Farm Committee that the system was one which ought to be tried at Sutton.

An experimental bacteria tank or filter (Fig. 1, Plate XLIIB.)—the first of its kind in the kingdom—was accordingly constructed under the superintendence of Mr. C. Chambers Smith, C.E., the tank being intended for the treatment of crude sewage, without previous treatment by chemicals or precipitation, the sewage being turned directly on to the filter as it leaves the outfall sewer, except that it is passed through roughing screens to intercept floating matter, such as paper, etc.

One of the precipitating tanks (Plate XLIIA.) was utilized for the purpose, the floating arm being removed, and the main effluent pipe used to draw off the filtrate.

The construction of a crude sewage filter or "bacteria tank," as it was termed, was commenced early in November, 1896.

Construction of the Filter.—The mode of construction of the filter was as follows:—On the floor of the tank, which has an area of 183⅓ super yards, was laid a 6-inch main trunk drain with 3-inch branch drains, nineteen in number, laid from the main running down the centre to the side walls. The main effluent pipe is provided with a 6-inch valve, which is a necessary adjunct so as to be shut down when the tank is being filled, and the valve is enclosed in a chamber for ease of access. On the pipes being laid, the joints, which, of course, are open, were covered with the coarsest ballast, and the tank was then filled up with ballast burnt from the clay which, as before stated, covers the whole site of the farm; the average depth of ballast in the filter being three feet six inches.

In filling the filter with the ballast care was taken to exclude all dust and material, which passed through a screen of a half-inch mesh. The following figures may be interesting and useful:—The area of the crude filter or bacteria tank is 183⅓ super yards; the capacity of the crude filter or bacteria tank is 218 cubic yards; the capacity of the filter without ballast is 36,094 gallons; the capacity for sewage of the filter with ballast is 13,500 gallons; the proportions being approximately one-third sewage, two-thirds ballast; the flow of sewage applied per superficial yard per day is 186 gallons; the flow of sewage applied per cubic yard per day is 138 gallons; the flow of sewage applied is at the rate per acre per day of 900,240 gallons. The first bacteria tank has been practically in daily work since the 21st November, 1896, treating on an average 30,000 gallons per day, the resultant filtrate being generally free from odour, the filter being charged twice, and sometimes three times per day.

Method of Applying the Sewage.—The whole of the sewage flow, without any chemical treatment, is turned directly on to the bacteria filter, the sewage having been passed through roughing screens to intercept the larger pieces of paper. Recently an automatic rotary screen (Fig. 517A), driven by a Poncelet wheel, actuated by the sewage flow, and manufactured by Messrs. John Smith & Co., engineers, Carshalton, Surrey, has been adopted with satisfactory results. The time occupied in filling one bacteria tank or filter is about three-quarters of an hour, and care is taken to prevent the sewage heading up or ponding above the surface of the filter, the flow being stopped as soon as the sewage level reaches to within a few inches of the surface of the ballast. The filter is then allowed to remain charged for two hours, after which the valve is opened and the filter is emptied, the time occupied in the latter process being about one and a quarter hours, the filtrate being then passed on to the secondary filters or over the land when any portion requires irrigating. The bacteria filter is then allowed a rest of two hours, after which it is again charged, the cycle occupying six hours.

Action of the Filter.—The action of the filter is biological, the sludge being absorbed by the action of bacteria in the filter, 57·2 grains of matter per gallon being on the average removed. The effluent from the second bacteria filter, which is composed of finer material, is uniformly clear and bright, almost resembling the majority of ordinary drinking waters, and this is generally turned into a brook of small volume without any further treatment whatever. The purification effected by the combined filters works out as follows:—

98·79 per cent. of matter in suspension removed.

85·83 per cent. of oxygen absorbed in four hours.

78·54 per cent. of reduction of nitrogenous organic matter as indicated by the albuminoid ammonia.

The first crude sewage or coarse bacteria filter has been working regularly since November 21st, 1896, twelve and a quarter million of gallons of sewage having been treated up to January, 1897, and 443

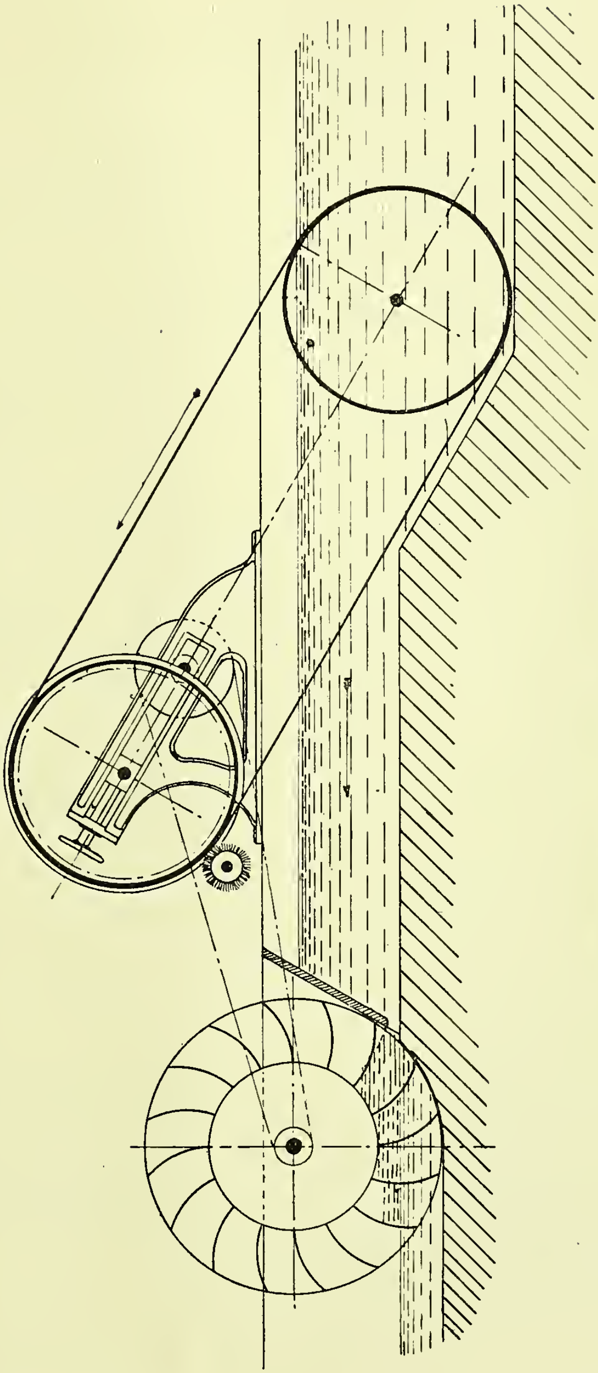


Fig. 517A.—Self-cleaning Sewage Screen (Smith's Patent), as used at the Sutton Sewage Works.

tons of sludge absorbed, without any nuisance, and at but little further cost than the opening and closing of the valves for the charging and discharging of the filter, and this latter appears to be in as good condition now as when it was first started, the filtering material itself being without more offensive odour than that of fresh garden mould.

Encouraged by the success achieved by the first tank, a second tank was converted into a bacteria filter and started in work on May 30th, but in this case the filtering material was laid in layers of varying degrees of fineness, the lower layers being the finest, and increasing in coarseness to the surface, the depth of material being five feet six inches; and although the cost of this filter is greater than the first, owing to extra labour involved in screening, the results hitherto have not been found superior to the first filter constructed. Four coarse grain bacteria filters have altogether been constructed, while one of Col. Ducat's self-aërating bacteria filters, having an area of 308 super yards, has also been constructed.

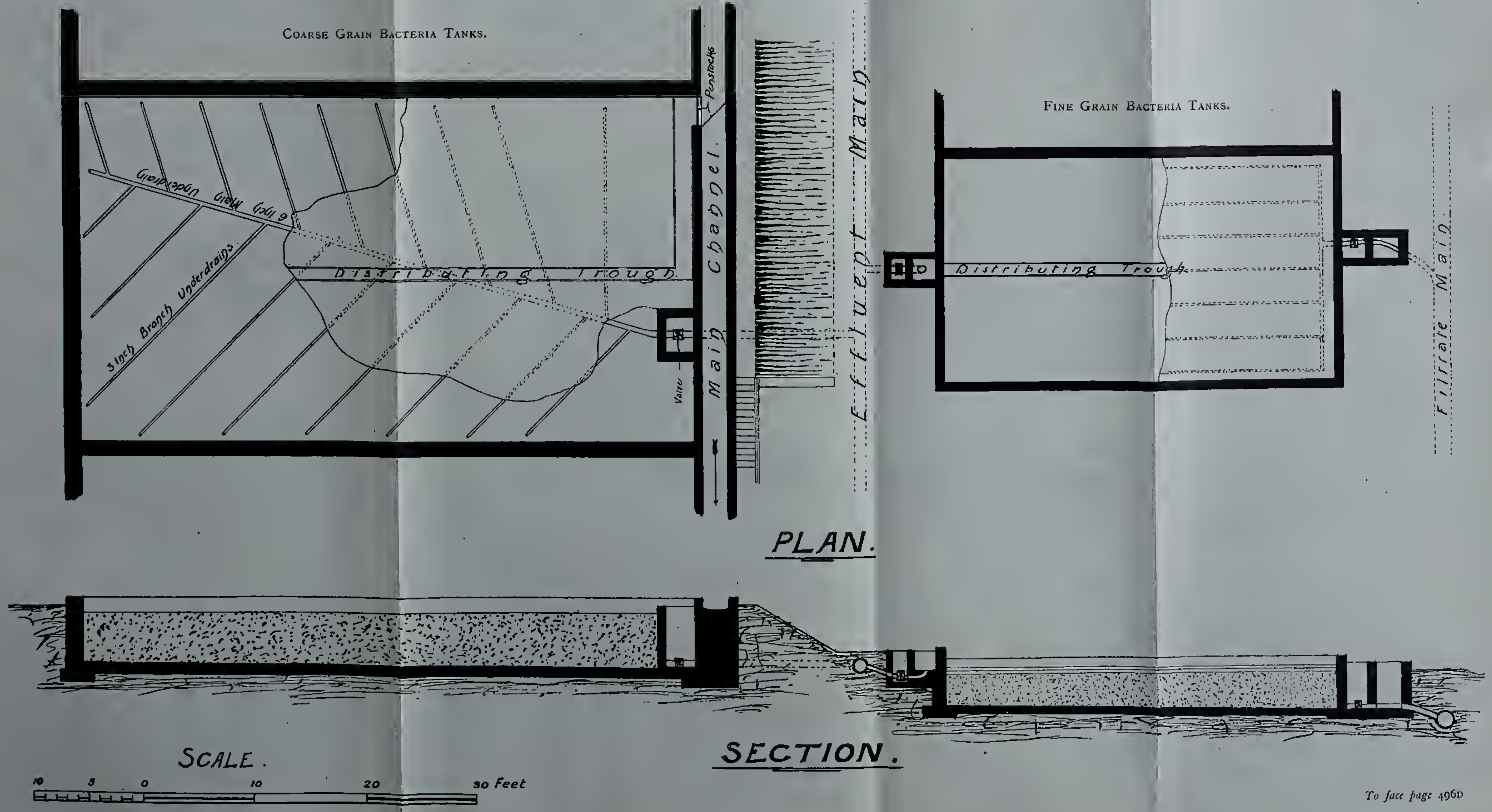
At the present time (June, 1898) 230,000 gallons of sewage are being treated daily by the biological filters. At a recent meeting of the Council it was resolved, on the report and plans of their engineer, Mr. C. Chamber Smith, to apply to the Local Government Board forthwith for a loan to defray the cost of construction of yet additional filters for the treatment of the whole of the sewage flow.

We may add that the Sutton system is not patented in any way, and is being adopted in numerous towns in the kingdom.

The above information and the general plan (Plate XLIIA., facing page 496), as well as the plan and sections of the bacteria tanks, have been kindly furnished by Mr. C. Chambers Smith, C.E.

Purification of Sewage by the Oxygen System, by W. E. Adeney, F.I.C., Assoc. R.C.Sc.I., Curator in the Royal University of Ireland; and W. Kaye Parry, M.A., B.E., Univ. Dub., A.M.I.C.E., M.I.C.E.I.

For some years the difficulties connected with the purification of sewage by filtration through land have become more and more manifest. There is no necessity to refer in detail to those difficulties. They are known to, if they have not harassed, every municipal engineer in the kingdom, and have driven sanitary authorities and district councils to their wits' end to comply with the demands of the Local Government Board, the county councils, and rivers pollution boards. The impossibility of complying with many of these demands for a purified sewage through land compels attention to other means, and at every gathering where the subject is discussed the consensus of opinion is that relief is only to be looked for at the hands of the bacteriologists, and that chemical science, with or without a minimum of land filtration, is capable of solving the problem how best to purify town sewage, whether


COARSE GRAIN BACTERIA TANKS.
FINE GRAIN BACTERIA TANKS.
Penstocks
6 inch Main Underdrain
3 inch Branch Underdrains
Distributing Trough
Main Channel
Valve
Effluent Main
Distributing Trough
Filtrate Main
PLAN.
SECTION.
SCALE.
10 5 0 10 20 30 Feet

ordinary, or combined with trade effluents. The authors of the Oxygen System claim to have solved the problem. The changes which water-carried sewage undergoes, when it finds its way into running water, or percolates slowly through porous soils, have for the first time been made the subject of a complete and rigorous experimental investigation, both in the laboratory and in experimental works, by the authors of the oxygen system. An account of this investigation has been published in the proceedings of the Institute of Civil Engineers of Ireland in 1896, and also in *Engineering*, vol. 61, pp. 728-730, and 762-764 (1896). The experiments described show not only what changes water-carried sewage, when exposed to natural agencies, undergoes, during its passage from a foul to a purified state, but also indicate clearly the conditions which must be provided for in works designed for the purification of such sewage.

A further result of this investigation has been to show that it is possible, by a new and simple method of analysis, to obtain data whereby the engineer may exactly estimate the nature and extent of the problem which the purification of the sewage of any locality may present.

The Scientific Principles of Sewage Purification.—It has now become accepted as a well-established fact, that the oxidation of sewage matters, and their eventful reduction to simple and harmless substances, are brought about by the operations of micro-organisms, and not by direct oxidation by the oxygen of the atmosphere, as formerly supposed.

It has been demonstrated that saprophytic organisms, *i.e.*, organisms which live on dead organic matters, the germs of which occur practically everywhere—in air, in water, and in ordinary soil—will quickly grow and multiply in water-carried sewage, and will rapidly set up an oxidation of the organic matters it contains, and change them into harmless forms of matter, provided that two conditions, essential to their healthy life processess, are maintained in the liquid during their activity. These conditions are :—

(1) A continuous and ample supply of air to all parts of the liquid, to afford the necessary oxygen to the organisms during their life processes.

(2) The preservation of the liquid in a neutral or slightly alkaline condition during the activity of the organisms.

When these two conditions are maintained in water-carried sewage, the organic matters it contains undergo two distinct stages of chemical change. During the first of these stages the organic matters suffer a complete alteration, and are almost entirely converted into carbonic acid, ammonia, and water ; only a small quantity of organic matter remains in solution at the completion of this stage, and it has been oxidized and so much changed in character from that of the matters originally present in the sewage, that it is no longer of danger to health ; it is, in fact, similar in character to peat and to the humus of ordinary soil.

The next stage of change which follows proceeds much more slowly. During its progress the ammonia originally present in the sewage, and that formed during the first stage of change, is gradually converted into nitric acid.

The investigation above referred to has shown that it is possible to determine the exact volumes of air required by the organisms to bring about each of these two stages of change in a given volume of a given sewage, and so obtain data for accurately estimating the nature and extent of the problem which the purification of the sewage of any locality presents.

Thus in the case of a very foul sewage it was found that 1,000 volumes of it, after the matters in suspension had been separated, required 1,400 volumes of air for the completion of the first stage of change, and a further 1,500 volumes for that of the second stage : in other words, the sewage, after the suspended matters had been separated, required nearly three times its own volume of air for complete purification through the agency of micro-organisms.

In the case of another sewage, which may be regarded as typical of an ordinary town sewage, it was found that 1,000 volumes of it required 625 volumes of air for the first stage, and 950 volumes for the second stage—in all, 1,575 volumes. In other words, this sewage, after the separation of the suspended matters, required one and a half times its own volume of air for complete purification by micro-organisms.

For all practical purposes it is unnecessary to carry the purification of sewage, within the purification works themselves, beyond the first stage of change, because the second stage proceeds so slowly that the organisms do not absorb oxygen as quickly as the water, in which the process occurs, can take it up from the air and dissolve it. Hence this part of the process of purification does not de-oxygenate water as the first does. It is also to be remembered that during the progress of this stage of change, which in reality is true nitrification, no conditions could be set up which would present danger to health. For these two reasons the second stage may be left to take place after discharge of the purified liquid from the purification works into a river or other water-course.

The problem, then, of the purification of sewage on a large scale, after the matters in suspension have been separated, resolves itself into supplying oxygen to the micro-organisms uninterruptedly during the progress of the first stage of change, which, as explained, they set up in the organic matters contained in the sewage.

In the absence of this uninterrupted supply of oxygen, we know too well the result. The organisms then set up changes of quite a different character, known as putrefactive changes, which are attended with the formation of bodies emitting most offensive odours, and with other conditions dangerous to health.

But one method has hitherto been available for supplying oxygen to large volumes of partially purified sewage in the manner required; it is that of filtration through sand, or gravel, or porous soil, or other suitable substance.

The process of filtration is, so far as sewage is concerned, now known to be simply an artifice or means of supplying air to all parts of sewage continuously during purification by organisms. The sewage, on passing through the filter bed, is broken up into thin films, which expose a very large surface to the air contained in the interstices of the filter. If these films be allowed to pass through the filter bed sufficiently slowly, the necessary supply of oxygen will be assured for their purification. But to ensure this condition for large volumes of sewage, extensive filtering areas must be provided, and very considerable labour must be expended upon them to keep them in efficient working order.

These conditions, it need scarcely be mentioned, render the process of filtration, when applied to sewage, extremely costly.

The filtration of sewage is attended, moreover, with certain dangers. These may arise from "channelling" of the filter beds, caused by frost, or by careless or insufficient attention, or they may arise from working the filters too quickly. Either condition will be followed by an effluent which ought not to be discharged into a river or other water-course.

The Oxygen System of Sewage Purification.—The Oxygen System is the result of several years of careful study on the part of its authors; it has been worked out principally with the object of providing a substitute for the filter bed, and of providing also means for preventing putrefaction in sludges.

The system possesses three distinct and novel features; they are:—

I. The use of crude manganese compounds for the purpose of clarification or precipitation.

II. The principle of recovering the chemicals employed for the precipitation.

III. The use of nitrate of soda, as a substitute for air (and therefore of the filter bed) for supplying oxygen to the organisms in the manner required by them.

I. The use of crude manganese compounds for the purpose of sewage precipitation is a very great and important advance in methods of sewage purification. So far as efficiency is concerned, they have long been recognised as the best known, but their cost has hitherto prohibited their use in the treatment of sewage.

They both completely deodorise, and effect a maximum reduction in quantity of *dissolved* organic matters in the sewage to which they are added.

But in addition to these properties the authors of the Oxygen System have shown by their investigations that manganese compounds possess two further properties of great importance to the problem of sewage purification which have hitherto been unrecognised. They are :—

(1) When employed as precipitating agents they give sludges mixed with the higher oxides of manganese, and these oxides have the property of acting as oxygen carriers to the micro-organisms, the growth of which are encouraged by the sewage solid organic matters contained in the sludge, and so prevent putrefactive fermentation being set up by the organisms in these organic matters, just as it has been explained atmospheric oxygen, or, as will be found explained later on, nitrate of soda, prevent micro-organisms from setting up putrefaction in the liquid portion of sewage.

The solid organic matters, when thus mixed with the higher oxides of manganese, undergo oxidation, and the oxides themselves are converted into carbonate of manganese, during any process of draining and air-drying to which the sludge may be subjected. After a time, when the oxidation has been completed, all that remains of the said organic matters originally present in the sludge, are brown oxidized organic matters resembling in all particulars the organic matters, or, as they are called, humus, of ordinary cultivated soils.

Sludges containing these oxides are absolutely non-putrefactive, and have been found to be valuable manures. They may be applied to land either before or after the process of oxidation above referred to has been completed.

In the case of works not situated in agricultural districts the sludges, owing to the complete absence of offensive smells, can be stored in heaps without offence to the neighbourhood, and when the process of oxidation is complete they may be burnt, also without offence, and the residue which remains, and which contains the manganese originally added, may be again converted by simple means into the form of a precipitant, and again employed for clarifying raw sewage.

(2) The second property of importance which manganese compounds possess in relation to sewage treatment is, they do not retard the after purification of the liquid portion of the sewage which has been clarified by their means, as is so marked an effect of compounds of alumina when employed for the purpose, but rather helps it.

The Oxygen Sewage Purification Company have obtained a patent for the manufacture of precipitants for the purification of sewage from the waste products, rich in manganese, of certain iron industries, and from other substances also rich in manganese, and are now in a position to supply a precipitant at ordinary market prices, to which the name Oxynite has been given, and which contains a high percentage of manganese compounds.

II. To render intelligible the value of the principle of recovery of the substances employed in the treatment of sewage under conditions other than those already explained, it is necessary to explain that in agricultural districts, when it is possible to readily dispose of the sludge to farmers, the Oxygen System employs a special form of tank, wherein the solid matters in suspension in the sewage are separated by mechanical subsidence and are deposited in the bottom of the tank ; the effluent from this tank is then treated in a second tank with the Company's new precipitant, for the purpose of completely clarifying it.

Two distinct advantages are secured by subjecting the sewage, when local conditions allow, to the process of mechanical subsidence ; they are :—

(1) Nearly all (about 90 per cent.) of the solid matters of the sewage are separated in their natural state, unmixed with precipitating chemicals ; the sludge is therefore about one-half the bulk of that usually obtained in sewage purification works, and for this reason gives rise to less difficulty in its disposal. It is, moreover, about double the manurial value of the ordinary sewage sludge. It has already been pointed out that this sludge can be rendered inoffensive by the addition of a small quantity of the second sludge containing the manganese compounds.

(2) The sludge obtained from the next operation, viz., chemical precipitation, contains comparatively little organic matter, and the chemicals co-precipitated with it may be easily separated from it by a simple patented process, and employed for action upon fresh quantities of sewage. The same chemicals may therefore be employed over and over again for the operation of chemical precipitation.

After the treatment with the Company's precipitant, the purified liquid is clear and free from odour, and is practically free from suspended matter ; the organisms existing in the crude sewage have also been largely, if not entirely, separated with the matters in suspension.

The organic matters which remain in solution in the partially purified liquid are of such a character that they can only be decomposed and converted into harmless forms of matter, on a large scale, through the agency of micro-organisms.

The object of the process up to this stage is to separate by subsidence and precipitation as much of the organic matters as possible, and to leave as little work as possible for the organisms to do.

III. As above stated, the next and final stage of treatment is carried on by micro-organisms, nitrate of soda being added to furnish the necessary supply of oxygen to them. The organisms have the power of decomposing this substance and of abstracting from it the oxygen they require. It is, in fact, a substitute for the air, as already explained, and it has the very great advantage that any sewage, partially purified, in which this substance is dissolved, carries with it its own supply of oxygen required by the organisms during their activity in it; hence there need be no fear that such a liquid will cause a nuisance in any watercourse that it may be discharged into, even if the complete alteration of the organic matters which the organisms effect during the first stage of their action upon them, as explained in the earlier part of this paper, has not been previously effected.

Trade Effluents.—During the last two years trials have been made for the purpose of demonstrating the value of the Oxygen System in dealing, not only with the ordinary house sewage, but with sewage from towns in the manufacturing districts which contains, in addition, the refuse liquids of paper manufactories, bleach and dye works, wool scouring factories, tan-yards, wire and galvanized iron works, and all the contaminations which pollute such rivers as the Mersey, the Irwell, the Calder, and the Aire. Subject to certain modifications as regards the chemicals employed, the mode of their delivery, and the construction and disposition of the tanks, according to the varying localities, the Oxygen System has proved its power of converting the foulest, most noxious trade sewage into a bright, clear liquid, harmless, odourless, free from organic and suspended matter. Not only will the Oxygen System deal with such sewage as a whole, but it will deal equally efficaciously with the single effluents from the works mentioned; there is therefore no reason why our streams and rivers should be polluted any longer by such effluents, either when allowed to flow individually into the nearest brook or watercourse, or collectively through the sewers of a manufacturing town, to be dealt with, at the cost of the ratepayers, at the outfall. If every manufacturing concern were compelled to purify its own effluent, which it could at a comparatively small cost by the Oxygen System, a large factor in rivers pollution would be removed, and local boards, district councils, and corporations would be saved the heavy burden of extra rates which the dealing with such effluents entails.

Tanks.—Each of the three processes referred to above—mechanical subsidence, chemical precipitation, oxidation — is carried on in a separate tank or tanks, the capacity of which is according to the quantity of sewage to be treated; for the method is the same whether thousands of gallons or millions of gallons are dealt with in the twenty-four hours. It may here be stated that the rate of flow is immaterial;

the construction of, and the connections between the tanks are such that as the crude sewage enters the first tank, so a correspondent quantity of effluent flows from the last tank by simple gravitation, when circumstances permit. One or more of the tanks, are built upon the Dortmund principle, and the use of these tanks, in so far as they form part of the Company's process, is protected by one of their patents. When this method of working is adopted, the sewage is conveyed down a pipe in the centre of a tank, which it thus enters at the bottom. This gives a much greater subsidence of solids, which may be further assisted where necessary by the use of baffle-plates, which will allow the liquid to pass upward only through the aperture between them and the sides of the tank. The tanks are circular, with a shelving bottom terminating in a sump, and they differ from those in general use for dealing with sewage, inasmuch as depth is required instead of a large surface area. This is an important matter for consideration where the outfall of a town has only a limited area in which the sewage can be dealt with. The process can also be used in connection with the ordinary shallow precipitation tanks in cases where it is not found convenient to use the deep circular tanks already described. In the Oxygen System a large acreage of shallow filtering and oxygenating beds is unnecessary. The works for dealing effectually with the sewage of a town of 100,000 population could by the use of the deep tanks be arranged in a space of fifty yards by fifty yards—no small advantage where the outfall area is circumscribed, or where land is not easily attainable. Nor need the sewage be dealt with entirely at the main outfall, for it can be treated at sectional points, and a stream of cleansing purity be turned into a watercourse or river.

No Large Buildings and no Heavy Machinery are needed.—When shallow tanks are used no machinery is employed, and even when the deep tanks are adopted the machinery is of a simple and inexpensive character, and this constitutes a great advantage when compared with the boilers, engines, pumps, etc., required by some systems. Where necessary, it can be arranged that the difference in level or loss of head between the invert of the sewer where the sewage enters the first tank and that of the conduit which carries away the effluent will be only a few inches, and no special raising of the sewage is necessary. The chemicals are delivered automatically. The apparatus used and patented by the Oxygen Company is the invention of their mechanical engineer, Mr. James Carson, and will effect the proper delivery of chemical, either in powder or in solution, in the most perfect manner. The power is obtained by a small water-wheel, worked by the sewage itself. In the machine for powder the chemical is placed in a hopper, which may be as large as is convenient, at the bottom of which, in the side, is a small opening, covered by a flap or door. On the opposite side of the hopper is a projecting lug, through which a vertical rod passes, raised at intervals by a cam-wheel, worked by the water-wheel. When the cam has lifted the rod to its highest point, it allows it to drop, thus giving a blow to the lug on the hopper, through which the rod is prevented from passing completely by a nut on its upper end. The blow thus given causes the flap-door to fly away from the hopper, and at the same time knocks out a quantity of the powder. The amount delivered at each blow depends on the distance the rod is allowed to drop, the size of the orifice in the hopper, and the weight used to keep the flap-door closed. The number of blows can be varied by altering the number of points on the cam-wheel. No arching of the powder takes place in the hopper, as the vibration of the blow knocks it down immediately if it should arch at any time. In the machine for feeding solutions the hopper is replaced by a small tank, in which the solution is maintained at a constant level, and the liquid is discharged through a balanced drop valve. There is no waste, even if the flow of sewage stops altogether, as the delivery only takes place at the moment of the blow, the valves, or doors, closing again immediately, and remaining closed till the next blow. The machines are capable of the most exact adjustment, and when once set require no further attention. When it is necessary in wet weather to treat large volumes of dilute sewage, the machine can be regulated so as to effect an economy in the use of the chemicals employed.

No Skilled Labour is required to work the Oxygen System, and very little labour of any kind is necessary. It has been shown that the delivery of the chemicals is automatic, regulated entirely by the flow of the sewage ; all that is needed is that the hoppers and cisterns in which the chemicals are placed shall be kept charged.

Adaptability of Existing Works.—It is an important feature of the Oxygen System that where there may be already an area of sedimentation or gravitation tanks they may be utilised to the fullest extent, and thus considerably minimise the cost of its application.

The Adaptability of the Oxygen System.—The Oxygen System for the Purification of Sewage is equally adapted for dealing with the sewage of large or small towns as a whole, with a sectional portion of that sewage, with the separate trade effluents of manufactories, or with the sewage of isolated buildings, such as hospitals, workhouses, asylums, or of private mansions. In the case of the latter establishments the installation will occupy the space of an ordinary coach-house and stable, or it can be put, as it is at Blarney Castle, below the ground, and so be effectually hidden from sight.

The Cost.—The cost of the application of the Oxygen System to the sewage of a large town compares most favourably with any other system, as no land for filtering is required, no expensive machinery, engines, or boilers, no extensive buildings needed, and a comparatively small space is necessary for the tanks. This reduces considerably the capital outlay. The cost of maintenance and working is also moderate, as all skilled labour is dispensed with; there is no outlay for fuel for boilers, for repairs of machinery, and there is no waste in the use of the chemicals employed. The water wheel referred to in the automatic apparatus worked by the flow of the sewage gives to it day and night the proper proportion necessary to effect the continuous purification, and no opportunity is afforded for a useless distribution of the chemical agents.

In 1889 the Chief Surveyor of the Board of Works, Ireland, acting on instructions, visited the principal sewage disposal works in England for the purpose of ascertaining the most suitable purification process for large public institutions. Shortly after his return the Oxygen System was brought under his notice, and in 1891 he recommended the Board of Works to adopt the system at the Criminal Lunatic Asylum, Dundrum, where it has been in operation ever since, to the entire satisfaction of the authorities. The Oxygen System has been adopted for treating the whole of the sewage of the town of Northallerton. It is also in use at the New Metropolitan Police Barracks at Chapelizod, and at Blarney Castle, the residence of Sir George Colthurst, Bart.

The Garfield Filter.—According to Dr. Geo. Reid, M.D., D.P.H., coal is used as the filtering material with very good results. The filter is five feet deep, and the coal is arranged in beds composed of particles of coal diminishing in size from the bottom upwards. Effluent drain pipes are arranged along the bottom of the filter in a 6-inch layer of coal nuts, about $\frac{1}{2}$-inch in diameter; this layer is blinded by a layer of coal of $\frac{1}{4}$-inch diameter A 9-inch layer of coal of $\frac{1}{8}$-inch particles follows, and above this is placed a bed one foot nine inches deep of $\frac{1}{16}$-inch particles of coal; the top layer is composed of two feet of coal dust which has passed a $\frac{3}{16}$-inch mesh. The sewage is allowed to flow continuously through the tank for twelve hours, and then the tank is aërated for twelve hours. The effluent is stated to be highly purified, and the capacity of the filtering power of the tank to be at the rate of 200 gallons per square yard, or about 1,000,000 gallons per acre in twenty-four hours.

TABLE 88.—"DIBDIN" AND "GARFIELD" FILTERS. MEAN RESULTS IN PARTS PER 100,000, WITH PERCENTAGE PURIFICATION.

Filter.	Oxygen absorbed in Four Hours at 80° F.		Percentage Purification.	Organic Ammonia.		Percentage Purification.	Nitric Nitrogen in Filter Effluent.
"Dibdin," April, 1894, to September, 1895	5·303	1·154	78·5	0·555	0·157	72·7	0·660
"Garfield," Wolverhampton, June, 1896, to May, 1897	4·159	0·324	91·8	0·431	0·075	79·8	0·623
"Garfield," Dr. Reid's inquiry, March 6th to June 14th, 1897 (means of six analyses)	0·650	0·171	73·6	0·200	0·039	80·0	0·860

The Salford Experiments.—The following account of these experiments has been furnished by Mr. H. Gilbert Whyatt, A.M.I.C.E., Deputy Borough Engineer, Salford :—

Experiments in the purification of sewage have now been proceeding for ten years, during which much time has been spent upon the trial of various patented processes, chiefly chemical, but all failures.

About five years ago the Borough Engineer, Mr. Joseph Corbett, induced the Committee to turn their attention to artificial filters, and experiments on modern lines were commenced.

Mr. Corbett believed at first that a very great deal of ventilation was essential to successful artificial filtration.

The first set of six filters were arranged at three heights, with a ventilation floor between each twenty inches of filtering material—total, five feet.

These filters were composed as follows—two of gravel and sand, two of coke breeze, two of cinders.

Very good results were at once obtained from all the filters, but, somewhat contrary to expectation, the cinders proved the best filtering media. The difference was very slight from day to day, but on the average the cinders were the best.

This first experiment was continued for fifteen months, at an average rate of 500 gallons per square yard per day while in use.

The results of that fifteen months' working, taking the average of a large number of analyses, were as follows :—

	In parts per 100,000.
Solids in solution	88·00
,, ,, suspension	0·
Free ammonia	1·29
Albuminoid ammonia	0·13

This was a very successful result to obtain.

Having carried out that experiment successfully, Mr. Corbett wished to prove the advantage of a preliminary roughing filter, and of varying degrees of aëration.

The filters were altered so as to have two, three, or four stories, and thus have different degrees of ventilation ; and that experiment is still being continued.

A record was kept of the analyses of the effluents from each filter, and it cannot be found that there is any practical difference between the effluents from these two, three, and four-story filters.

In this second set the method of passing the tank effluent on to the filters was changed. During the first set the effluent was delivered from troughs embedded in the filters, using sufficient sand on the surface to make the water pass evenly over the surface; but in the second set a series of wooden troughs was arranged a couple of feet or so above the top, so as to scatter or sprinkle the effluent like rainfall over the surface of the filter.

The attendant was thus enabled more readily to rake the surface of the filters. These filters have been very successful. Mr. Corbett tried them at varying rates of flow, from 500 gallons to 1,400 gallons per square yard per day, with this somewhat curious result—that so long as the filter did not choke up, the quality of the effluent was almost uniformly good.

Once in a while the filter would suddenly choke up within a couple of days, and refuse to take the sewage ; but it was almost invariably found that by simply leaving the filter idle for a week or two it would recover itself, and again take the sewage perfectly. Mr. Corbett argues by analogy that just as a pure water filter in a waterworks covers itself with a glutinous film, so these aërated filters become filled throughout with a glutinous mass of bacteria, through which the sewage will not pass. By giving the filter a rest for a week or two the surplus population is starved out of existence, the filter recovers itself, and goes on as well as ever. In October, 1895, two filters of eight feet deep were made in order to ascertain whether a deeper mass of filtering media would deal with a larger quantity of effluent : it was found, speaking generally, that whereas a five-foot filter will deal with and purify 500 gallons per yard daily, an eight-foot filter will deal with 800 gallons. These eight-foot filters are made of cinders (furnace clinkers?) which pass through a riddle of two meshes to the inch, and are retained by a riddle of six meshes to the inch, so that the small cinders range from one-eighth to one-third of an inch in diameter, all dust being thus kept out, as well as large pieces.

These two eight-foot filters are laid upon an open floor, to begin with, which, by the way, must never be waterlogged. Above this open floor was placed the filtering medium, one size only from bottom to top, as just described. One of the pair was divided into four heights, with ventilation floors ; the other was not divided. Upon a series of analyses of the results, it was found that the difference was exceedingly slight, but what there was, was just in favour of the filter without ventilation floors. Consequently Mr. Corbett comes to the conclusion that the simplest and cheapest-constructed filter is the best. In August, 1896, during Mr. Corbett's absence, the manager of the sewage works received orders to run these experimental filters continuously, without any time whatever for rest and aëration, the object being to test the filters to the point of destruction. Contrary to all expectation, the filters stood even that severe test, and the filters were run practically continuously for twelve months from August, 1896, at the rate of 1,000 gallons per square yard daily, then for a short time at 500 gallons, and now at 700 gallons; the only rest they are allowed being a short time daily whilst the small centrifugal pump supplying them is stopped for the purpose of cleaning and oiling. [A definite rest of a few weeks was given them during the early summer of 1897, whilst the engine was overhauled and repaired, but work was resumed on the same lines as just mentioned.]

In place of the sprinkling troughs Mr. Corbett now uses spray jets with a head of four-feet pressure, which throw the sewage over the surface almost like rain. The surface of the filter is a perfectly open surface, and water is not allowed to collect anywhere.

If the water does begin to collect in any small depression on the surface, the attendant at once rakes cinders upon the place.

Up to June, 1897, the average analyses for two years were :—

	Parts per 100,000.
Free ammonia	0·483
Albuminoid ammonia	0·137
Oxygen absorbed in four hours ...	0·625

One indication of the satisfactory condition of the filtrate is that the filtrate channel from the filters is coated with a thin green moss, and that there has been no growth of the brown sewage fungus since 1895, except for very small periods and small quantities.

These bacterial filters have been protected by a "roughing" filter of fine gravel, its purpose being to arrest any floating fats or unprecipitated sludge which may find its way through the subsidence tanks.

This roughing filter has to be cleaned every one or two days.

A word as to the tank effluent which has been purified by these bacterial filters.

During the filtration experiments some twenty-five or more precipitation experiments have been tried, many of them with various chemicals, and the remainder with varying quantities of lime. Some of these have cumbered the roughing filters more than others, but the effluent of every process was passed through the bacterial filters with good results. (*Cf.* "Proceedings Municipal and County Engineers," vol. 23, page 253.)

The Salford Corporation consider the system so satisfactory and certain that they have resolved to spend £80,000 in altering the works and laying down bacterial filters ; but the Local Government Board have refused to sanction such an expenditure unless the Corporation include a sum to cover the purchase of a sufficient quantity of land over which the filter effluent may be turned and further purified.

Septic Tank System.—" In this system no chemicals are employed, and there is no 'treatment' of the sewage in the ordinary sense of the term ; its purification being accomplished entirely by natural agencies.

" The septic tank itself is merely a receptacle designed to favour the multiplication of micro-organisms and bring the whole of the sewage under their influence. To this end the tank is of ample size, though not larger than would be necessary with chemical precipitation, and covered so as to exclude light and, as far as possible, air. The incoming sewage is delivered below the water level ; and the outlet also is submerged, with the twofold object of trapping out air and avoiding disturbance of the upper part of the contents of the tanks. On entering the still water of the tank the solids suspended in the sewage are to a great extent disengaged, going either to the bottom or to the surface, according to their specific gravity. In the absence of light and air, the organisms originally present in the sewage increase enormously, and rapidly attack all the organic matter. By their action the more complex organic substances are converted into simpler compounds ; and these in turn are reduced to still simpler forms, the ultimate products of the decomposition in the tank being water, ammonia, and carbonic acid and other gases. Other nitrogenous compounds may also be present, but they will all be soluble in a slightly alkaline solution—a condition which obtains with every normal sewage.

" The works established at Belle Isle, Exeter, deal with the sewage from those parts of the parishes of St. Leonards and Heavitree served by the St. Leonards sewer, the total population being 1,500. During dry weather the daily quantity of sewage disposed of was found by careful gaugings to amount to 35,000 gallons, and the average for twelve months in round numbers works out to nearly 54,000 gallons a day. The plant consists of a septic tank (Plate XLIII.), 64 feet 10 inches long, by 18 feet wide, by 7 feet to 7 feet 9 inches depth of water ; and five filters, four of which form the working set, one being held in reserve, to permit of each filter in turn having a period of rest. In speaking of the different stages of the work done, Mr. Cameron designates the flow from the tank as the 'effluent,' and the discharge from the filters as the 'filtrate.' The sewage flowing into the tank is not subjected to any screening whatever ; on the contrary, special provision is made for the uninterrupted passage to the tank of the contents of the sewer.

"In the tank, at the inlet end, two grit chambers, ten feet deep, are formed, and the inlet pipes are carried halfway down these chambers. The outlet from the tank is by a pipe with a slot cut in its side, extending the full width of the tank, and terminating in a gauge-well outside it. The gauging is done by one of the late Professor James Thomson's V notch gauges.

"The tank is covered in with a concrete arch, in which are placed air-tight manhole covers and plugged openings for taking samples and for measuring the depth of the deposit; and in the body of the tank an inspection-well, in the sides of which are placed glass windows to enable the contents of the tank to be viewed. The only outlet from the tank is by the slotted pipe, which is situated fifteen inches below the water level.

"On the top of the sewage in the tank a scum is formed, consisting of the floating matter undergoing decomposition. During the winter this scum attained a thickness of from three to four inches, forming a rugged and coherent layer of considerable toughness, the surface of which was covered with a variety of fungoid growths; but as warmer weather set in it gradually dwindled down to rather less than an inch in thickness. The heavier suspended matter, consisting chiefly of road grit, settles at the bottom of the tank, together with the insoluble residue from the decomposition of the sewage solids. Careful measurements of this deposit made on the 31st August, 1897, showed the quantity to be about 66½ cubic yards. The bulk is considerably swollen by the gases which are formed during the decomposition of the organic matter still adhering to the deposit, which would bring the whole mass to the surface were it not that the residue is heavier than water, and sinks again to the bottom as soon as it is sufficiently loosened to allow the escape of the gas. In addition to its own decomposition, the deposit is thus subjected to a continual washing action, by which it is ultimately reduced to an inert and inoffensive ash.

"Examination of the deposit in the permanent tank shows its composition to be as follows:—

Moisture	88·14	per cent.
Mineral Matter	7·91	,,
Loss on Ignition	3·95	,,
	100·00	

"The dry solid matter in the tank amounted at the time of examination to about five and a half tons, of which two-thirds are mineral matter, the remaining third being made up of water of hydration, carbonic acid gas, and a little organic matter not as yet decomposed. The flow through the tank up to 31st August having been about twenty and a quarter million gallons, the solid matter in the deposit amounts to 4·3 grains for every gallon which has passed through ; adding 0·2 grains for the very small amount of dry solid matter in the scum, we have in the tank 4·5 grains per gallon of flow to that date.

"The most exhaustive examination of the sewage, so far as suspended solids are concerned, has been made by Messrs. Dibdin and Thudichum, who found in thirteen samples collected over 24-hour periods, in April and June last, an average of 24·5 grains per gallon, 10·0 grains being returned as mineral matter and 14·5 grains as organic. Comparing this figure with the amount of solid matter found in the tank, we find that no less than twenty grains per gallon have disappeared, the organic matter in particular having been almost entirely removed. The net loss of dry solid matter over the whole year amounts to about twenty-six tons, or eighty-one per cent. of the whole.

"If, instead of destroying the suspended solids by bacterial agency, they had been converted into sludge, there would have been 556½ cubic yards of 90 per cent. sludge to dispose of, the production being estimated at one cubic yard per 1,000 persons per day, the average rate ascertained by Mr. W. Santo Crimp in several cases examined by him.

"Thus, the tank does away with the necessity for chemicals and filter-presses or other apparatus for disposing of sludge, and produces an effluent which can be filtered without risk of clogging the filters.

"The effluent, after flowing from the gauge-well, passes into a shallow aërating trough, over the sides of which it falls in thin sheets into channels leading to distributing wells. In these wells valves are placed, controlling the flow to the distributing channels on the surface of the filters.

"The filters, Plates XLIII. and XLIV., page 512, have each an area of eighty square yards, and a depth of five feet ; collecting drains are laid on the bottoms of the filters, joining main collectors, the latter terminating in discharging wells. In the case of filters Nos. 1, 2, 4 and 5, the filtrant is broken furnace clinker, and in that of No. 3 broken coke.

"Filtration with these filters is not by a continuous flow in and out ; but when the filter is receiving its dose of effluent, the outlet valve is shut down, so that the filter gradually fills up, and remains full till the next filter is filled, when it is discharged. This was the method adopted by Mr. Dibdin at Barking. The filters are filled and discharged automatically (Plate XLV.). As the filter fills, the filtrate from it at the same time rises in its discharging well ; from these discharging wells small pipes are led, discharging over two pairs of buckets attached to rocking shafts. To these shafts are also attached the valves which control the flow to and from the filters. The filter which has just filled discharges the one standing full, at the same time shutting the outlet and opening the inlet valve of the filter to be filled, and so on. All the manual attention required is when setting to work the resting filter, involving, say, fifteen minutes' work at intervals of two or three days.

"The filtration of sewage or sewage effluent is not a mere straining action. If it were so, the filters would soon clog and become useless. Moreover, the effluent from the septic tank, being free from solids, is not susceptible of improvement by straining. The work to be done consists in the oxidation of the ammonia formed in the tank. This is thus converted into nitric acid, which at once combines with the bases present to form nitrates.

"This oxidation, like the previous decomposition, is the work of micro-organisms, but of a kind totally different from those which operate in the tank. The latter are largely of the species classed as anærobic, living in the absence of air and light, and exercising in many cases a reducing or deoxidising action. The organisms which work in the filter, on the other hand, are ærobic, the presence of oxygen being absolutely necessary for their life and work. Consequently the conditions prevailing in the tank must be reversed in the filter, to which oxygen must be freely supplied.

"To this end the filters are best constructed of some porous material, such as coke breeze or crushed furnace clinker, affording abundant interstitial space."

According to Mr. T. H. Pearmain and Mr. C. G. Moor, M.A., Members of the Society of Public Analysts, "the following Table shows the percentage purification produced by the 'Septic Tank' process according to different observers as judged by the removal of albuminoid ammonia and oxidizible matters."

TABLE 89.

Authority.	Albuminoid Ammonia.	Oxidizible Matters.
Dibdin and Thudichum	63·2	80·9
Dupré	84·9*	88·3
Pearmain and Moor	80·0	90·0
Perkins	64·4	78·7
Rideal	77·0	82·0

The great advantage of this system is that the sludge is got rid of.

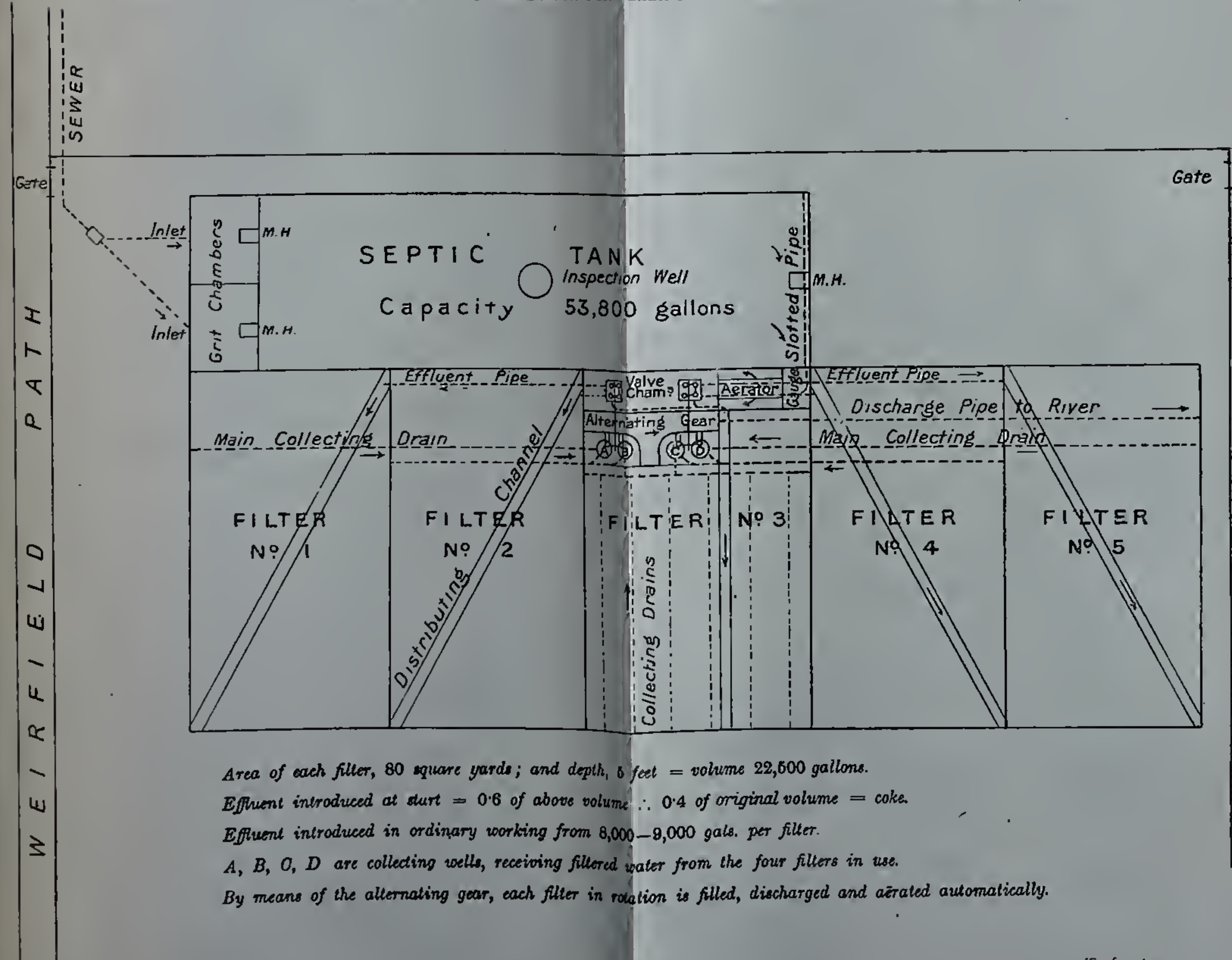
The Local Government Board has recently signified its sanction to a loan for carrying out the Exeter sewage scheme, which has been designed on the Septic Tank system.

Aërated Bacterial Self-acting Filter (Colonel Ducat's patent).—The general arrangements and details of these filters are shown in Plates XLVI. to XLVIII., p. 514. The filter is designed to effect the oxidation of the sewage by arranging for it to drip like rain through the filtering beds;

* Organic Nitrogen.

SEPTIC TANK FILTRATION.

SKETCH PLAN OF THE SEPTIC TANK AT BELLEISLE FOR DEALING WITH THE SEWAGE OF ST LEONARD'S, EXETER.



Area of each filter, 80 square yards; and depth, 5 feet = volume 22,500 gallons.

Effluent introduced at start = 0·6 of above volume ∴ 0·4 of original volume = coke.

Effluent introduced in ordinary working from 8,000—9,000 gals. per filter.

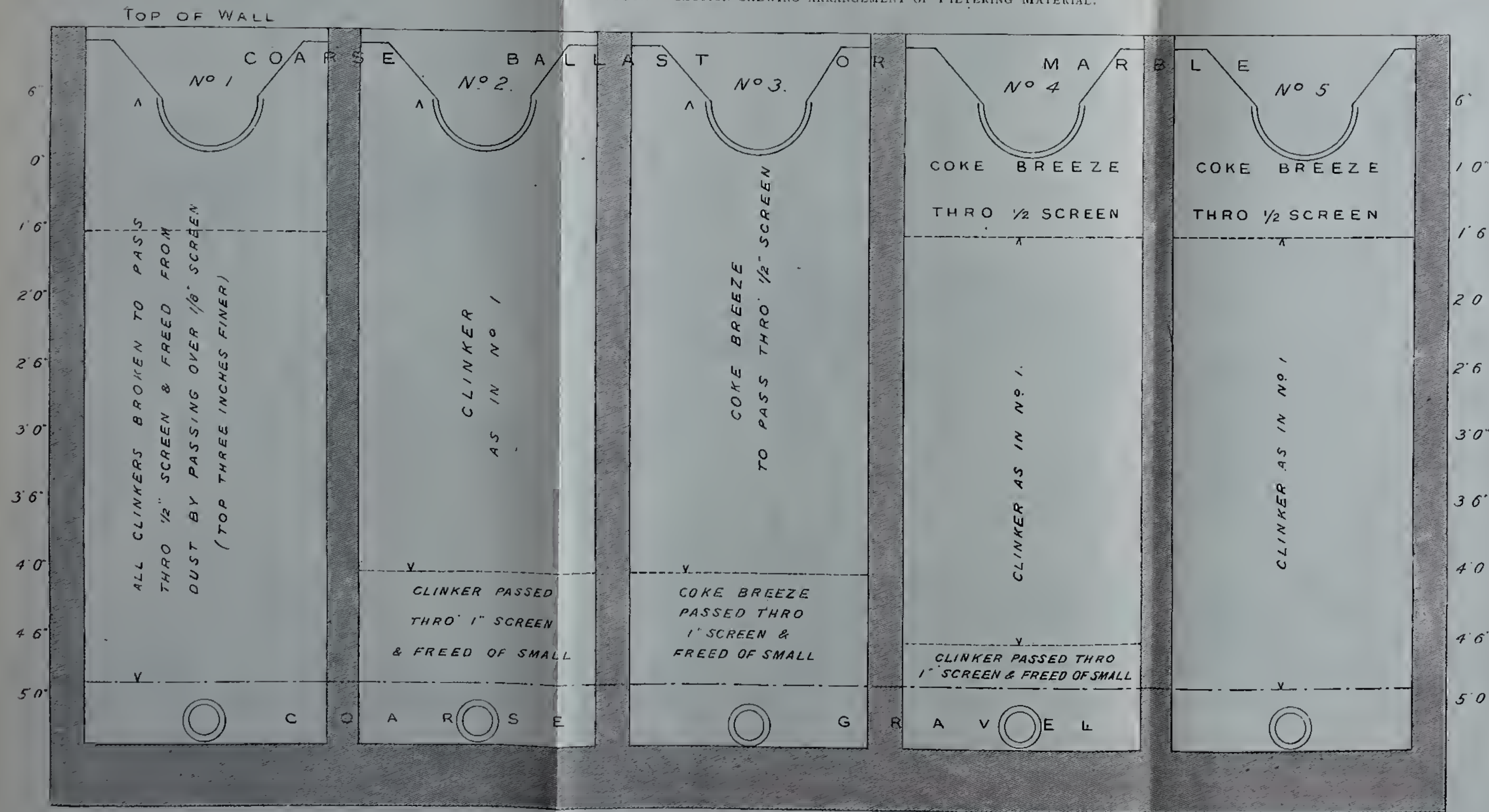
A, B, C, D are collecting wells, receiving filtered water from the four filters in use.

By means of the alternating gear, each filter in rotation is filled, discharged and aërated automatically.

To face page 512.

SEPTIC TANK FILTRATION. SECTION SHEWING ARRANGEMENT OF FILTERING MATERIAL.

PLATE XLIV.



To face page 512.

SEPTIC TANK FILTRATION, AUTOMATIC ARRANGEMENTS.

PLATE XLV.

CYCLE FOR FOUR FILTERS, NOS. 1, 2, 3, AND 4, DISCHARGING INTO FOUR COLLECTING WELLS, A, B, C, AND D.

At starting let filter No. 4 be already full and resting, and No. 1 filling. — Period I.
When No. 1 fills it overflows into tipper C, discharging No. 4, putting down outlet valve of No. 3, and admitting effluent to No. 3. — Introducing Period II.
When No. 3 fills it overflows into tipper B, discharging No. 1, putting down outlet valve of No. 2, and admitting effluent to No. 2. — Introducing Period III.
When No. 2 fills it overflows into tipper D, discharging No. 3, putting down outlet valve of No. 4, and admitting effluent to No. 4. — Introducing Period IV.
When No. 4 fills it overflows into tipper A, discharging No. 2, putting down outlet valve of No. 1, and admitting effluent to No. 1. — And so on.

DIAGRAM OF OVERFLOW PIPES.

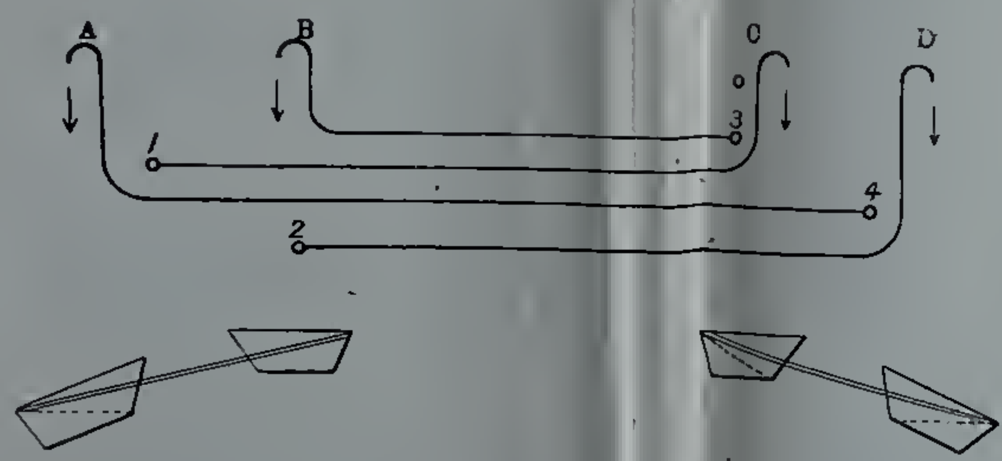
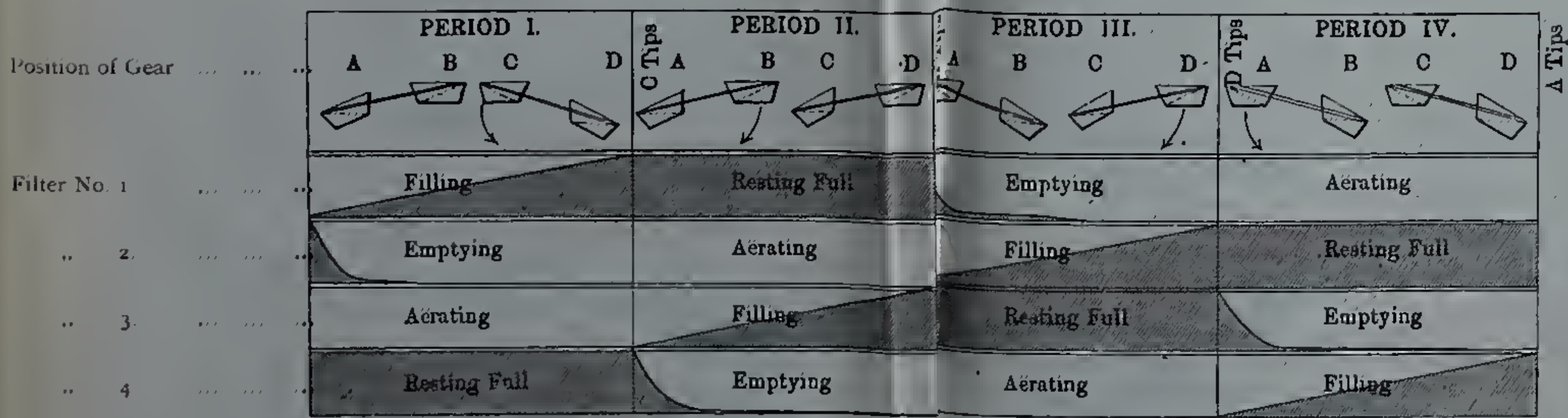


DIAGRAM SHOWING SUCCESSIVE STATES OF FILTERS CORRESPONDING TO SUCCESSIVE POSITIONS OF ALTERNATING GEAR.



To face page 512.

access for the air is given at the sides of the filter bed by inclined pipes. During the winter the air supplied has to be warmed, and it then becomes necessary to cover the side pipes by means of a wooden screen, and the air is admitted after heating by a furnace underneath.

By this method of disposal, the sewage taken direct from the sewer, without any preliminary treatment, is run on to a specially prepared filter of an inexpensive construction, where by the life action of micro-organisms, the sludge or solid matter in the sewage is broken down and liquefied, in which condition much of the carbon, combining with oxygen, forms carbonic acid gas, which is dissipated inoffensively in the atmosphere ; and much of the nitrogen in the sewage combines with the hydrogen, forming ammonia.

In this aerated filter, which is specially designed for the purpose, the process of purification by oxidation is fostered and furthered ; the nitrogen of the ammonia and of the organic matter, in combination with the oxygen of the air, which this aerated filter alone can supply automatically in sufficient quantity, forms nitric acid, which combines with the lime, soda, potash, or other suitable base in the sewage forming nitrates or nitrites, which are entirely harmless in the effluent.

This elaborate process of the laboratory of nature is practically utilized and applied in the most scientific but at the same time the very simplest and cheapest manner possible.

The sewage, without precipitation of sludge or treatment of any kind whatever, merely runs on to the filter direct from the sewer, and in about three-quarters of an hour, issues from the base of the filter an effluent, bright, purer than is attainable from any known precipitation process, absolutely inodorous, and fit to go into any stream without causing offence or injury of any kind.

It will thus be seen that, for the perfect disposal of sewage, no precipitation of sludge is required, no chemical treatment is necessary, no mixing machinery, no houses, no costly settling tanks, no sludge pumps or presses with the unavoidable offence attending the manipulation of sewage sludge and the difficulty of disposing of it afterwards, and no large staff of highly-paid labourers, but the whole process of purification is automatic and very simple.

As this method of sewage treatment dispenses with the use of lime or other chemicals which might be injurious to fish life, it will be found especially well adapted for use at the numerous seaside places where valuable oyster beds or fishing banks are endangered by the discharge of untreated sewage in their vicinity and where the problem of the substitution of a harmless effluent is very difficult of solution.

Sewage purification cannot be effected more inexpensively than by this process, which it will be seen at once, costs nothing to work, for the filtering material never wants washing or changing, but finality appears at last to have been reached in sewage disposal.

This biological filter, suitably arranged, is equally applicable to the purification and filtration of water for dietic purposes ; and not only can a purer, better filtrate be obtained than can be got by any process of ordinary sand filtration, but much economy can be effected by the saving of the expense of sand washing, etc. The coarse sand or pebbles, crushed quarry chips, cinders, or other materials used in the filter never require to be washed or renewed, the necessary purification being effected biologically by the action of the micro-organisms which cause the purification of the water itself, and the same bright, colourless effluent will always continue to be given off, in fact, improving if possible, the longer the filter is in work.

The facility with which the same high degree of purification can be obtained, at a very trifling cost for fuel, during a long severe frost, when any ordinary filtration would be impossible, will, in many cases, make this filter especially valuable.

This filter can now be seen at work at the Sewage Works, Hendon, within an easy drive of London, and inspection is invited.

The bacterial analysis of the effluent from the filter at Hendon has made it perfectly clear and certain that any required degree of purification can be obtained by this method of treatment, and rank sewage can be rendered as chemically pure as a high class drinking water. It is merely a question of adapting the height of the filter to the quality of the sewage to be treated and the purity of effluent desired, but that a very foul sewage can be rendered pure enough for all practical purposes by treatment in a filter eight feet high, is shown by the chemical analyses which have been made.

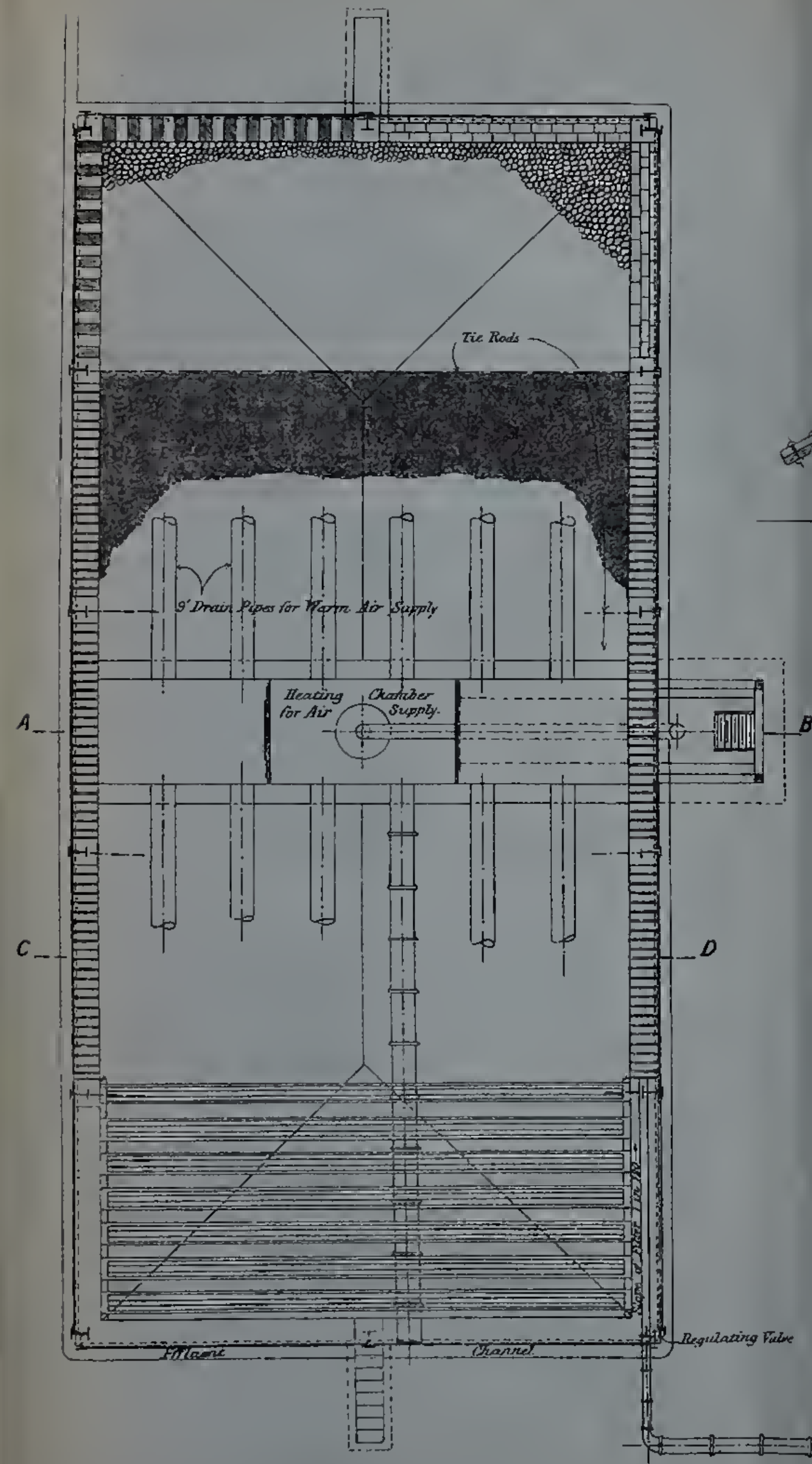
The capacity of the filter is stated to be 250 gallons per yard super in twenty-four hours, or about 1,000,000 gallons to the acre, and the cost of work is the wages of one man per 1,000,000 gallons a day, and the purchase of a little coke for warming the air supply in winter. Experimental filters have been made at Hendon and Sutton, Surrey.

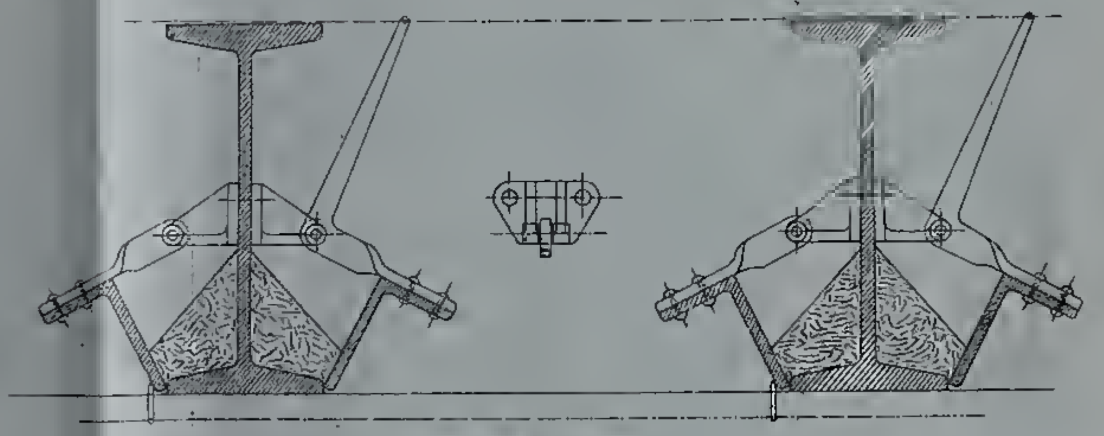
The Purification of Sewage by Bacterial Oxidation and Forced Aeration, by Colonel Geo. E. Waring, M.I.C.E.—The following description of the process has been furnished by the patentee :—

" For those living upon the sea-coast or close by the channel of some great river, the selection of a method of sewage disposal is usually a simple matter. Where the natural conditions are favourable, free discharge into a strong tidal current or into a water-course sufficient in size to insure ample dilution, swift enough to prevent deposits, unobstructed in its flow and not used as a source of domestic supply, will be considered,

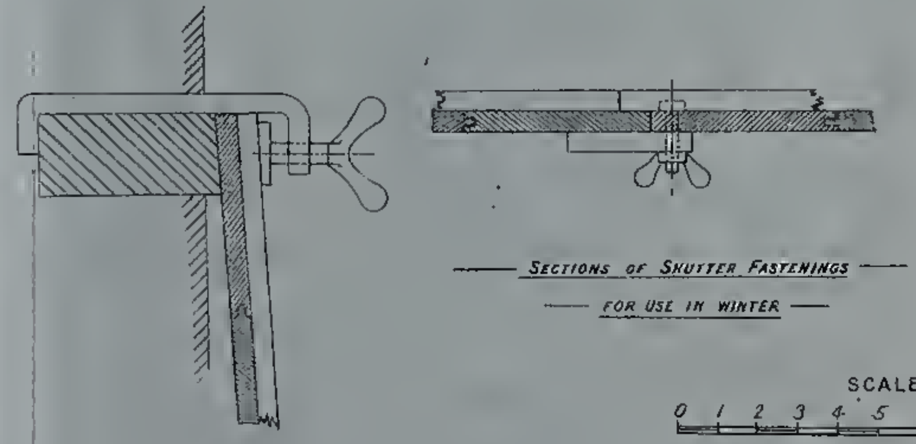
AERATED BACTERIAL SELF ACTING FILTER.

A TYPE FOR VILLAGE OF 2000 INHABITANTS.



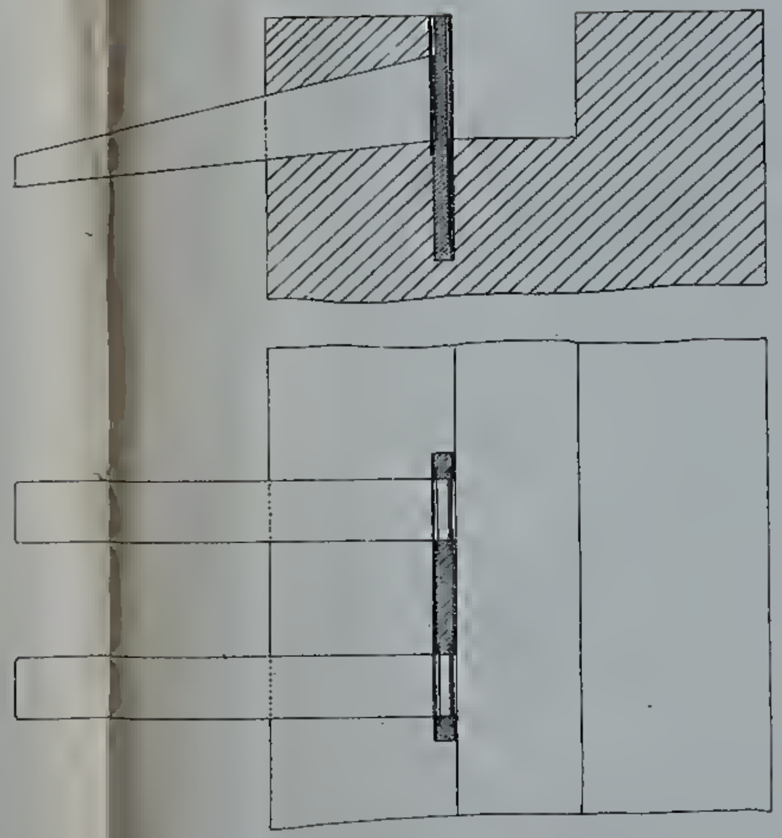


DISTRIBUTING CHANNELS.

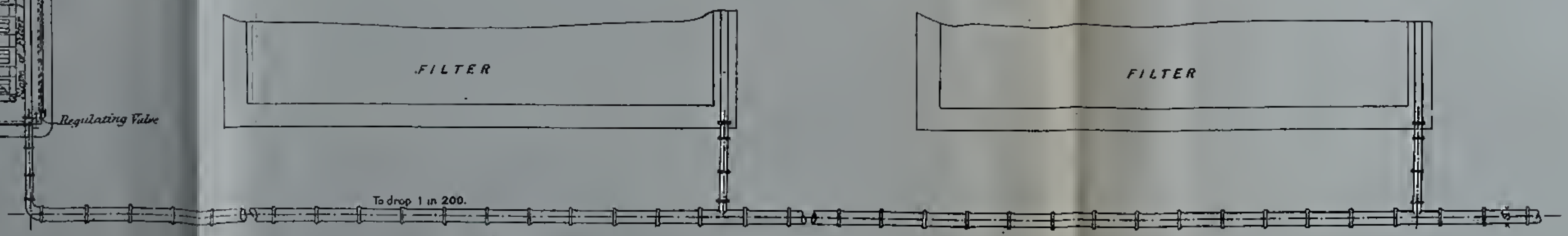


SECTIONS OF SHUTTER FASTENINGS FOR USE IN WINTER

SCALE
0 1 2 3 4 5 10 INCHES



SHEWING (LIFT UP) REGULATING VALVE

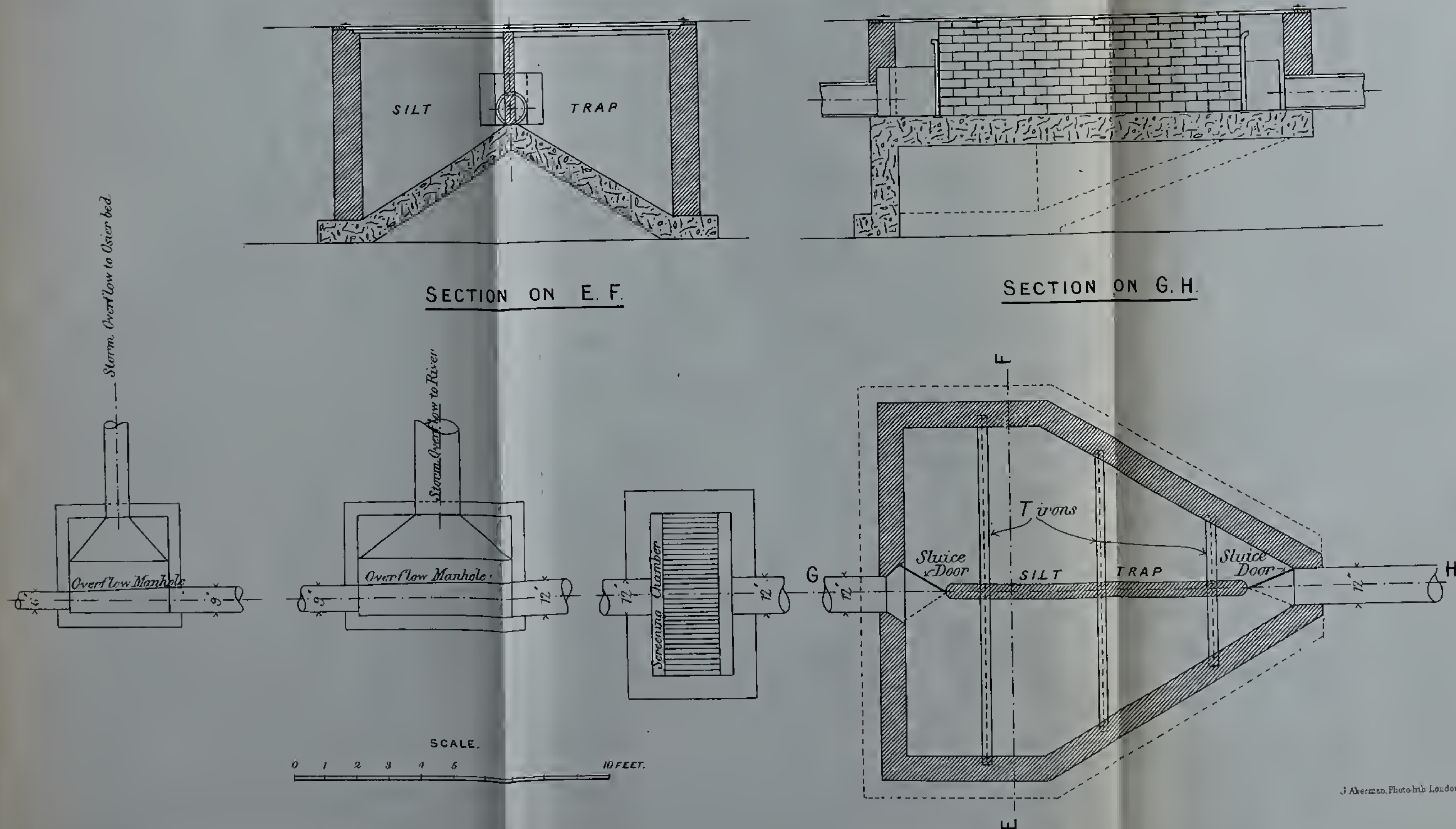


SCALE.
0 1 2 3 4 5 10 FEET.

J Akerman, Photo-lith London.

AERATED BACTERIAL SELF ACTING FILTER.

A TYPE FOR VILLAGE OF 2000 INHABITANTS.

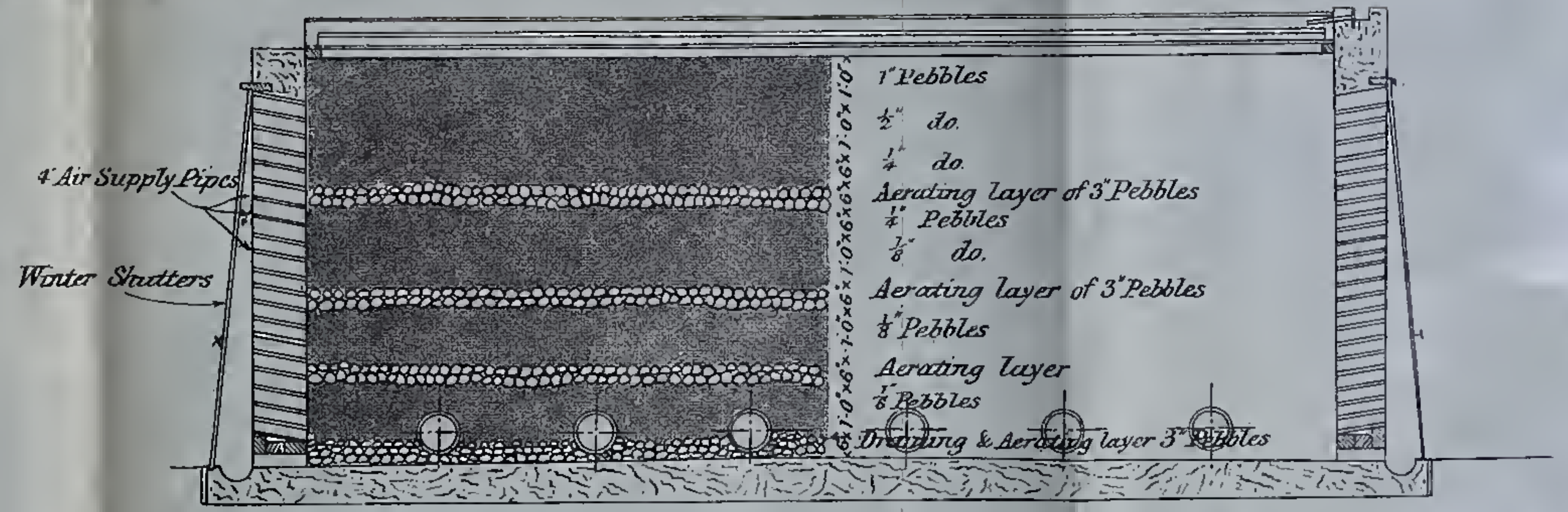


J. Akerman, Photo-lith. London.

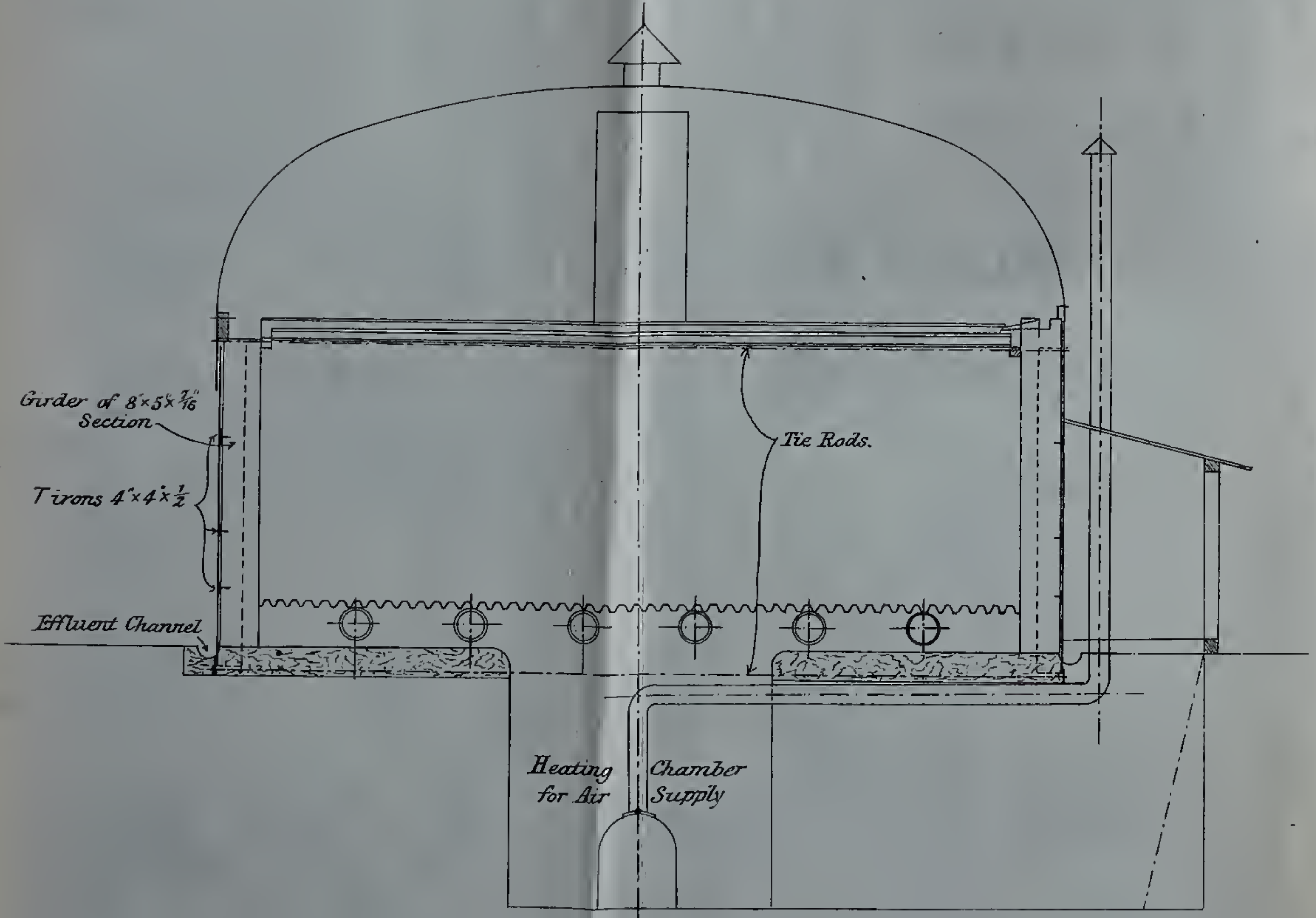
AERATED BACTERIAL SELF ACTING FILTER.

A TYPE FOR VILLAGE OF 2000 INHABITANTS.

PLATE XLVIII.



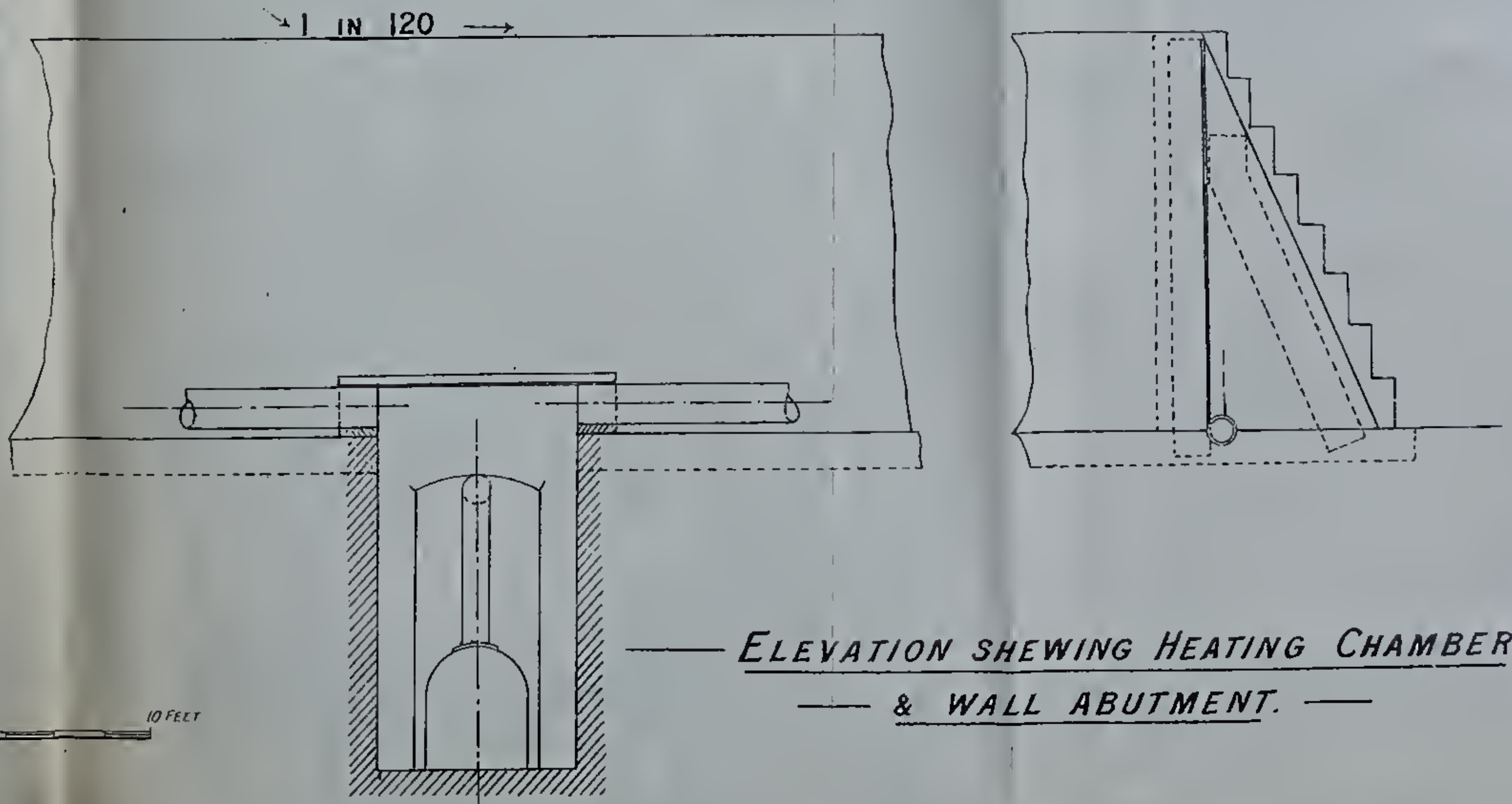
SECTION ON LINE C.D.



SECTION ON LINE A.B.

SCALE

0 1 2 3 4 5 10 FEET



ELEVATION SHEWING HEATING CHAMBER & WALL ABUTMENT.

TABLE 90.—SHOWING THE RESULTS OF THE CHEMICAL ANALYSIS OF THE "EFFLUENT" FROM COLONEL DUCAT'S AEROBIC CULTIVATION FILTER.

RESULTS EXPRESSED AS PARTS PER 100,000. TO OBTAIN GRAINS PER GALLON, MULTIPLY BY 0·7.

Date.	Total Solids.	Free Ammonia.	Albuminoid Ammonia.	Oxygen absorbed from Permanganate in :—		Oxydised Nitrogen.	Remarks.
				1 hr. at 23° C.	5 hrs. at 23° C.		
Collected, 3/8/97. Examined, 4/8/97.	136	0·95	0·08	0·56	0·64	2·28	The effluent was remarkably clear and transparent, and entirely free from objectionable odour. The cloudy appearance usually associated with sewage effluents was here practically absent. The suspended matter appeared to be very small in amount.

A. C. HOUSTON, M.B., D.Sc.
August 6, 1897.

TABLE 91.—SHOWING A COMPARISON BETWEEN THE CRUDE SEWAGE AND THE EFFLUENT FROM COLONEL DUCAT'S AEROBIC CULTIVATION FILTER.

Samples Collected, 3/8/97. Examined, 4/8/97.	Ammonia.			Oxygen absorbed from Permanganate.		Remarks.
	Free Ammonia.	Albuminoid Ammonia.	Sum of the two Ammonias.	In 1 hr. at 23° C.	In 5 hrs. at 23° C.	
Crude Sewage	12·00	7·60	19·60	29·00	59·00	Very turbid, full of solid matters, having an extremely offensive odour.
Effluent........................	0·95	0·08	1·03	0·56	0·64	Practically odourless, clear and transparent, very little suspended matter visible.
Difference per cent.	92	98·9	94·7	98	98·9	Difference per cent.

A. C. HOUSTON, M.B., D.Sc.
August 6, 1897.

probably for a long time to come, the cheapest and best course that can be adopted.

"Much graver consideration, however, is needed for the solution of the problem confronting the vast number of communities which are situated upon the smaller water-courses of the country, or are remote from all streams.

"A wider diffusion of sanitary knowledge has resulted, rightly, in condemning as criminal the cesspool, formerly considered an humble—but honest and necessary—member of the body politic. A general introduction of abundant water supplies, followed almost invariably by an overlavish use of water for domestic purposes, has created a demand for sewers to remove liquid wastes. Those sewers must have an outlet. Awakened public sentiment has demanded—and is demanding with constantly increasing urgency—that the original purity of the brooks and rivers be maintained; and in one State after another, Legislatures are adopting strict measures to secure this end.

"As a result, the great majority of the inland cities and towns are being brought face to face with conditions which are daily becoming more and more serious, and the natural drainage channels, which seem to be the most convenient means of relief, are being closed by legislative act. One community cannot with impunity allow its wastes to pollute the soil, water, or air of another.

"Evidently but one thing remains to be done. It *must consume its own wastes upon its own property*, and pass on to its neighbour water as pure as it received. This can be accomplished. In 1,000 parts of sewage 998 parts are pure water, one part is composed of innocuous mineral matters, salt, etc., and the remaining one part, *which alone has the power of becoming offensive*, consists of dead organic matter. This matter is complex in structure, but the materials of which it is built are simple mineral substances which have been appropriated for a time by a living plaut or animal, and which, having served a term of usefulness, are rejected. Their ultimate destiny is disintegration and the return of their elements to the mineral world, to begin again, when occasion offers, the cycle of life, death, and decay. This disintegration is as important in the economy of nature as are the processes of life. Without it the organic world would soon lie buried in its own filth, and the supply of plant food would become exhausted. The materials needed for the growth of organic structures are loaned, not given; and when the building ceases to be useful, it must be torn down and its materials must be returned to the common store-house.

"This process of demolition can be effected only by oxidation. A complete result could be attained, theoretically, by the application of fire, which is simply rapid chemical oxidation; but it is obvious that the purification of sewage by this means is impracticable. Nature accomplishes the same complete result by a biological combustion. In this process, the reducing agents are minute living organisms, which tear apart the complex products of life, and combine the elemental carbon, hydrogen and nitrogen with the oxygen of the air, forming carbonic acid, water, and nitrous and nitric acids.

"Bacterial disintegration may be accomplished, broadly speaking, in either of two ways ;—by decomposition or by putrefaction. (There are many intermediate forms of change, which merge one into the other, so that a sharp line of division between these processes is impossible.) Both accomplish the same final result—the resolution of organic tissues into their component elements. This end is reached by progressive changes. In decomposition these changes are inoffensive and innocuous ; in putrefaction the intermediate products are disgusting and possibly dangerous. This distinction must be kept clearly in mind.

"The essential difference between these processes is that, in the former, the reducing bacteria are of a kind which require for effective work the presence of abundant air, while in the latter little or no air is needed for the operations of its agents. An organic structure breaks down under decomposition, its constituents combine with atmospheric oxygen to form carbonic acid, water, and innocuous mineral salts. As similar matter is disintegrated by putrefaction, the elements, set free in the absence of air, recombine and form offensive compounds, some of which are poisonous. It is the latter process which produces disgusting, and probably dangerous, conditions in sewage which has been stored in mass, as in a cesspool.

"But decay in one of the two forms is inevitable. The sooner it is accomplished, and the more direct the manner, the better will be the result. We can delay it—we can postpone the end for a considerable time—but we cannot alter the final outcome. We can treat sewage with disinfectants which will stop the work of disintegration, but it will commence again as soon as the antiseptic agent is weakened by dilution, evaporation, or other cause. Such treatment results only in shifting the scene of the decay. It simply transfers the possible evil from the present to the future—from our own territory to that of our neighbours.

"A far wiser course is not to retard but to hasten the natural processes of decomposition (using always the word in its literal scientific meaning, namely—resolution into the original component mineral and gaseous elements) by providing conditions most favourable to the complete and rapid breaking up of the organic structure. Bacterial oxidation, when properly controlled, insures complete freedom from offence and danger. It can be made to produce any necessary degree of purification ; for, not only are the solid impurities of sewage removed by the energetic scavenger bacteria, but even the filth which is in solution is attacked and destroyed, under favourable conditions, so that the water of the foulest sewer can be made as pure as that of the mountain brook.

"To accomplish this natural purification, it is only necessary to bring the sewage into contact with light, well-aerated soil. The reducing bacteria always abound in the sewage itself, in the surface soil and in the air, and oxygen, the only other essential, is freely supplied by the atmosphere. When sewage is spread over a natural surface, it is important that it be applied in thin sheets and intermittently, so that every particle of the liquid and of the soil may come in contact with air. This is the process known as 'Broad Irrigation.' It has been used so widely, and with such signal success, that further description is unnecessary. Where abundant land is available, it is the system *par excellence* for sewage treatment. Its application, however, necessitates the purchase and preparation of considerable ground. The land must be sufficiently well drained, naturally or artificially, to afford free escape for the descending water, and carefully graded so that the distribution of the sewage may be uniform. Under good management, one acre will purify the wastes of from five hundred to one thousand persons.

"Where sufficient land, suitable for irrigation, is not available, 'Intermittent Downward Filtration' is sometimes used. This is not a different process, but only the same process intensified one step; for the purifying agents and the necessary conditions are the same, namely,—reducing bacteria and abundant aeration. In it, the purification is effected, not only on the surface of the soil, but also under the surface; for in a properly constructed filter-bed the material is so porous that, as the applied sewage sinks away, the air which follows it can penetrate the mass and make bacterial oxidation possible at a considerable depth. By thus extending downward the zone of bacterial activity, the capacity of a given area is much increased; for the purification depends upon the exposure of the sewage, for a certain length of time, to the action of the oxidizing organisms; and it is obvious that, without reducing this period of exposure, sewage can be passed more rapidly through a deep layer of purifying material than through the shallow layer upon which the process of irrigation depends.

"Intermittent application of the sewage is necessary, in order that the water may drain away and air enter the pores of the soil. While one area is undergoing aeration, the flow must be diverted to other tracts, which, after use, must be aerated in like manner.

"Under this process, one acre of beds will purify the sewage of from fifteen hundred to three thousand people. That its capacity is thus limited is owing, not to the great amount of impurity which is contained in the sewage, but, principally, to the length of time required for penetration of the filtering material by the air. Absorption from the atmosphere is, necessarily, a slow process, and until air has reached the innermost recesses where organic matter is stored, the purifying process in these places cannot begin. The amount of oxygen available for nitrification is, moreover, limited ; for, when once the pores of the soil have filled with air, the underground atmospheric circulation is so slight that fresh oxygen is not supplied to take the place of that which has been used, and the gaseous products of the decomposition are not carried away, but remain to hinder to a constantly increasing extent the purification which is taking place.

"In 1891 it occurred to the writer that the capacity of a filter-bed might be increased by supplying artificially the air needed for the stimulation and sustenance of bacterial action. It seemed probable that the use of air under pressure would not only insure the introduction of oxygen to every part of the filter, but would make it possible to change its gaseous contents as often as might be found desirable.

"To determine the value of this theory, an experimental plant, on a practical working scale, was erected and put in operation, at Newport, R.I., in 1894. In outline the double process consisted, first, of the mechanical deposition in filter-beds of all solid matters carried in suspension in sewage, and their subsequent destruction by forced aeration ;—and second, the further and complete purification of the clarified sewage by bacterial oxidation of its dissolved impurities in an artificially aerated filter.

"The details of the construction and operation of this plant have already been published.* It is sufficient for the purpose of this paper to say that the results accomplished exceeded the most sanguine expectations. It was found that one acre of artificially aerated filters would purify the wastes of from ten thousand to twenty thousand people.

"The sewage used (pumped from the main outfall sewer of the city) contained not only the fresh wastes normally present, but the putrid overflow of many old cesspools ; yet the liquid leaving the tanks was clear, white, odourless and tasteless. It was collected in a large tank where discoloration would have been at once apparent, and in this tank fish lived and thrived. Engineers and committeemen drank of it freely and pronounced it good, and frequent chemical analyses proved it actually pure—a good drinking water. An average of the figures representing the purification accomplished showed that 92·5 per cent. of the organic matter was removed. At one time a removal of 99·08 per cent. was effected. As the total organic impurity originally in the

* "The Purification of Sewage by forced Aeration," which can be obtained in pamphlet form on application to the writer at Newport, R.I., or to The D. A. Tompkins Company, Charlotte, N.C.

sewage was but $\frac{1}{1000}$th part of the whole mass, this degree of purification means that the water escaping from the filters contained but ·0000092 part of objectionable material.

"This complete regeneration continued through five months until the experiment was concluded. The filtering material was never renewed, yet when the tanks were taken apart it was found to be as clean and sweet as beach-washed gravel. There was absolutely no suggestion of the hundreds of thousands of gallons of sewage which had passed through it. The filth had completely disappeared. It had been broken up into harmless mineral elements, some of which had escaped into the air, while the rest passed out with the effluent water.

"At the close of the experiment the plant was moved to Providence, enlarged and installed in the yard of the Silver Springs Bleaching and Dyeing Company, to purify for dyeing purposes the water of West River, a small stream much polluted by the wastes of a large woollen mill upon its banks a short distance above the bleaching works. The results of this use have been entirely satisfactory, and a series of comparative tests in dyeing certain very delicate shades indicates that the filter effluent is fully as good as distilled water for this purpose.

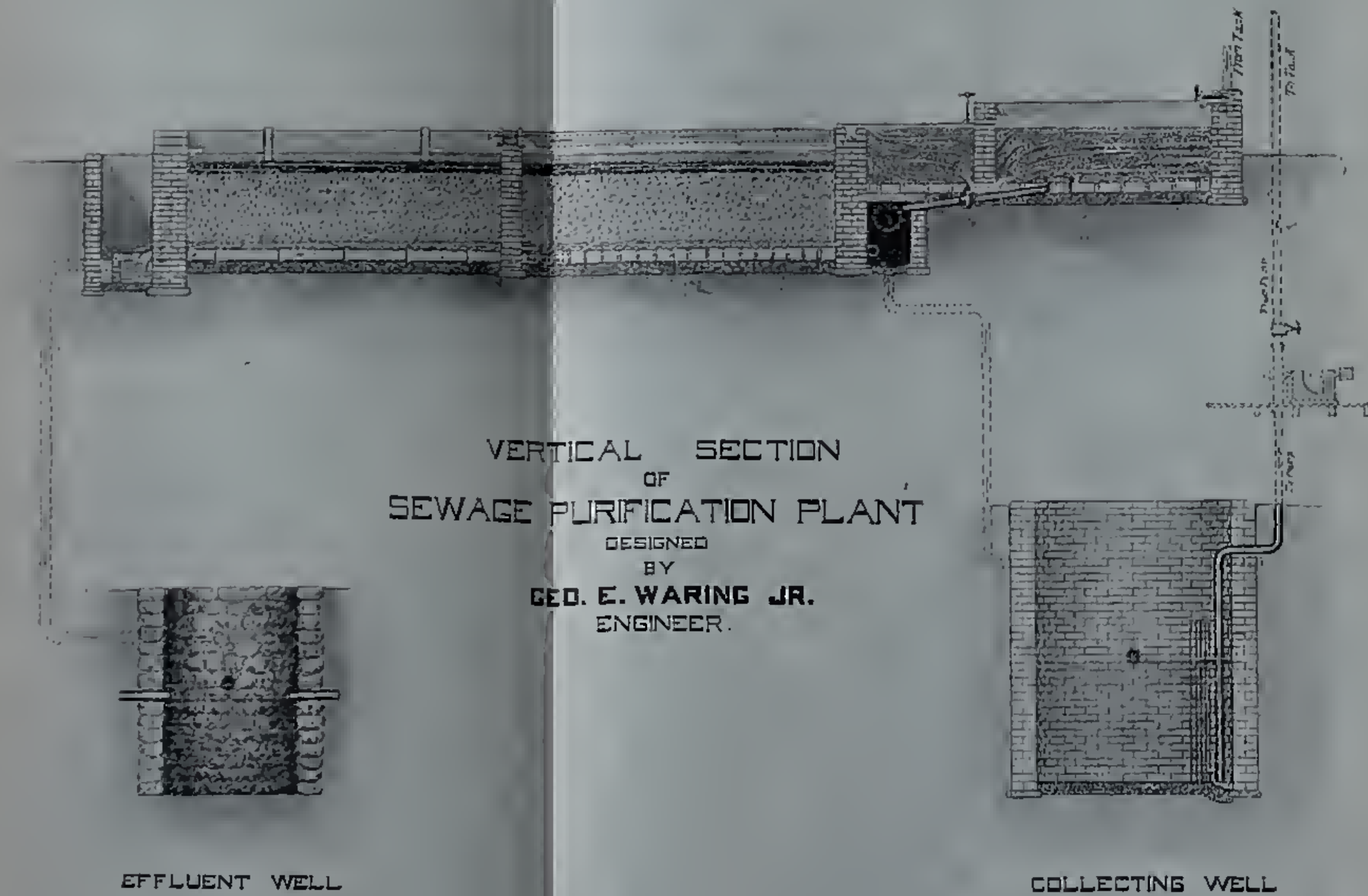
"In Plate XLIX., the two small beds on the right are the 'strainers' in which the solid matter is caught and consumed. The sewage may be supplied by direct gravity flow, or pumped from a collecting well direct or through an overhead tank as conditions may require.

"The two left hand beds are for the destruction of the soluble organic matter, so that the final effluent is no longer sewage but pure and drinkable water. Not only is it in *appearance* as clear and sparkling as a mountain spring, but it is in *fact* free from organic or noxious chemical contamination and of a standard purity better than the average water supply in which it originated.

"In the Plate the effluent is shown as leeching away into the soil; but it is frequently used for street sprinkling, landscape decoration, in pools, fountains, brooks, cascades, etc., etc. But for the sentiment attaching to it, it might be used with impunity for any domestic or mechanical purpose.

"The chamber shown in solid black serves the double purpose of an air channel communicating with all the beds, and a drainage vault through which the strainers, when periodically emptied, return their contents into the collecting well.

"Early in the spring of 1897 the writer was called upon to advise concerning a serious problem of sewage disposal at Willow Grove Park, Penna. This is a popular pleasure ground of one hundred and ten acres, lying in a basin at the foot of the Chelten Hills, fifteen miles north of Philadelphia, on the old York Road. It is owned and con-



To face page 520.

trolled by the Union Traction Company, of Philadelphia, whose directors have done all that genius and money could accomplish to make the spot attractive. The park was opened in 1896, and vast crowds of people visited it. It soon became apparent that there was grave need of suitable means of sewage disposal. Lavatories and toilet rooms lay scattered in all parts of the grounds ; a large restaurant poured forth a volume of liquid waste ; dairies and ice cream pavilions furnished contributions of wash-water, and the sewage from the car-barn and employee's quarters (Willow Grove is a terminal) added considerably to the flow. The liquid is somewhat less dilute than ordinary town sewage, for no laundry or bath wastes enter the system. The total amount is estimated as 80,000 to 100,000 gallons per day.

"The only water-course in the neighbourhood is a stream that runs through the gronnds, feeding an artificial lake and lily ponds. At times, in summer—unfortunately when the flow of sewage is greatest—this stream is dry, and at no season of the year is it sufficiently large to warrant the discharge of sewage into it. Its average flow would pass through a four-inch pipe. Furthermore it is dammed a short distance below the park to make a lake for boating in another garden resort.

"Under these circumstances, some method of artificial treatment was necessary. The only land available for irrigation was a tract nearly a mile away and considerably above the level of the park. To reach it involved the laying of a long force-main and heavy pumping. The soil of the surrounding country is a deep bed of stiff clay, not suitable in its natural condition for disposal by irrigation, and absolutely unfit for intermittent filtration. The use of the latter process would have necessitated the artificial construction of the entire set of filter beds, covering about one acre, with material brought from a distance.

"The system of filtration with forced aeration, which required about one-eighth of this area, was, therefore, adopted. Plans were completed in March, and the work of construction began early in April. The plant is located on the Union Traction Company's property, just outside of the trolley-road which encircles the park, and close beside the railway power-house.

"As the sewage cannot reach the filters by gravity flow, it is collected in a receiving well (under the pump and tank house shown in Plate), which has a storage capacity of about 12,000 gallons. The essential feature of this well as related to the filters is its system of screens, designed to withhold such substances as rags, paper, corks, lemon skins, etc., which are inoffensive in themselves and which would encumber the filter beds needlessly. These screens also serve to detain the coarser putrescible matters until they are so softened and broken up as to pass the mesh. A finely divided condition favours their ultimate destruction in the filters. Two screens are used. The first and outside of these is formed of $\frac{5}{8}$-inch vertical iron rods, half an inch apart, and is fastened permanently in place across the entrance to the chamber surrounding the suction pipe which empties the well. The inner screen is a frame of flat iron, well braced, covered with galvanised iron netting of $\frac{1}{4}$-inch mesh. It slides into grooves of channel-iron built into the walls of the chamber, so that it can be lifted out for such occasional cleansing as may be necessary. A second pair of grooves, close to the first, is provided to receive a duplicate screen which is lowered into place before the fouled one is removed. It has been found, in practice, that one of these fine screens will pass sewage for six or eight weeks without clogging.

"From this well the sewage is pumped to a distributing tank upon the roof of the building and directly over the well. A small centrifugal pump was originally installed for this work, and, save for a little occasional difficulty in priming, its service was satisfactory. Later, for reasons which concerned the policy of the power house management, and which had no connection with its efficiency, a steam piston pump was substituted for the electric centrifugal. A fan blower supplying air to the filters has always been driven by an electric motor, fed from the trolley current.

"From an outlet in the bottom of the distributing tank, the sewage runs by gravity to the filter-beds. The rate of flow is controlled by a valve under the tank, and this is adjusted so that, under normal conditions, the sewage will accumulate gradually in the tank during the day, to escape at night when the amount of incoming sewage is greatly reduced. In this way a more or less constant flow is maintained throughout the twenty-four hours.

"The filtering material is contained in shallow rectangular beds, with walls of masonry and concrete floors. Over each floor extends a system of channels (made of hollow Raritan tile, laid loosely, with open joints) which collect the water and lead it to its outlet, and which also serve to distribute throughout the filter the air furnished by the blower.

"The process of purification comprises two distinct operations, one withholding and destroying all the organic matters carried in suspension in the sewage, and the other removing the impurities in solution. The same change—bacterial oxidation—takes place in both operations. It is simply more convenient, for mechanical reasons, to allow the flow to pass through two filters, each especially designed for its peculiar work, than to carry on complete purification in one filter.

"The first of these filter-beds, called the 'strainer,' is divided into two compartments by a diaphragm wall, which does not rise from the floor but is built upon the false flooring of hollow tile, so that liquid and air can pass freely under it from one compartment to the other. Each bed is filled with broken stone, ranging in size from ½-inch to 1-inch average diameter. (A thin layer of coarser material is placed at the bottom over the tile, to protect the open joints of the latter against the entrance of obstructing particles.) The sewage, admitted through gates in the distributing main, passes down through the receiving compartment, rising in the smaller or discharging compartment and overflowing into a collecting channel formed in the top of the heavy partitioned wall. The rate at which it travels is so slow that suspended matters are deposited upon the extended surface of broken stone, forming the filtering medium. This action is purely mechanical, a mere strianing out or deposition of the sludge. As these deposits gradually form, the flow becomes less free, and the level of the sewage rises in the receiving compartment, the increase of head counterbalancing the increased resistance. This condition is accompanied by no deterioration in the quality of the effluent, but, on the contrary, the purification is usually a little better at this stage than when the filter was first started; for the layer of sludge on the surface of the receiving compartment acts as a finer filter, and prevents the passage of even the most minute particles. Eventually a point is reached where with all the head available, the liquid cannot be forced through fast enough to carry off the incoming sewage. The flow is then turned into another strainer of similar construction, where the process of deposition begins anew. There are three of these strainers in all, only one being shown in section. Any two of them, used alternately, are sufficient for regular service, one straining while the other is being cleansed. The third is intended as a reserve in case of emergency; but, in order that it may be always in good working condition, all three strainers are used, one at a time, in rotation.

"As soon as a strainer becomes clogged and is thrown out of use, drainage valves are opened and the liquid contents drain away, passing back through a drainage chamber (shown in black) with trapped outlet, to the collecting well for further treatment. (The total amount returned to this well is inconsiderable, for the tanks are drained infrequently and the quantity at each draining is small, being merely that which fills the voids between the broken stone in one of the beds.)

"As soon as the water has escaped, air from the blower (which is connected with the drainage chamber, the inlet being shown by the large dotted circle) rushes through the distributing channels underlying the filtering material, and rises through the interstices, supplying speedily to every part the oxygen necessary for bacterial activity. Oxidation at once begins; each particle of filth is attacked by the purifying organisms, disintegrated and resolved into innocuous and inodorous gases or soluble mineral compounds. As an abundant supply of oxygen is maintained, the bacteria multiply rapidly, and in a short time—long before its next period of use comes around—the entire accumulation of filth disappears, and the bed is able to receive and pass sewage as freely as when it was new. This alternate clogging and cleansing proceeds indefinitely. As the accumulated sludge dries and cakes on the surface—usually on the second or third day of aeration—it should be broken up, to facilitate the circulation of the rising air. With proper care, especially in the exclusion of silt, the work of the filter will be uniformly good, and no removal of sludge or renewal of the filtering material will ever be necessary.

"As the sewage leaves the strainer, it is free from suspended matter, but is slightly milky or opalescent in appearance. It still contains all the impurities originally in solution. It is collected by a channel, formed in the wall which separates the double strainers from the larger beds, or 'aerators.' This channel discharges into an iron pipe, which delivers the clarified sewage at the centre of the aerator area, where valves control its distribution through copper gutters in four directions. The function of these aerators is to remove dissolved impurities from the strainer effluent. Drainage and air channels of hollow tiling, which collect the purified water and also distribute air from the blower, cover the floor. Over them, the filling of filtering materials—mainly crushed coke—are placed. The whole is covered with a layer of sand, which serves to retard and distribute the flow. The liquid passes through this blanket of sand slowly, and trickles down, in thin films, over the surfaces of the particles of filtering material, finally escaping through a trapped outlet. In its descent it is in constant contact with the current of air, which, introduced at the bottom of the tanks, is continually rising through the voids between the particles and escaping through vent-tiles, which perforate the surface layer of sand, as shown in the Plates.

"In the aerators, which work continuously and not alternately, filtration and aeration are carried on simultaneously. The bacteria, which soon establish themselves upon the particles of the filtering material, are in constant activity, being fed by the organic matter in the descending sewage and supplied with air by the ascending blast from the blower. The liquid is subjected to their foraging for about an hour—the period required for its slow percolation through the mass. During this time its dissolved impurities are destroyed, and the only trace of previous contamination left in the effluent is the high percentage of nitrates, which indicates—not innocence, it is true—but complete repentance and regeneration.

"The purified water is collected as it leaves the aerators, and carried to an effluent well, which is connected by an underground channel with one of the lakes in the Park, so that the water can be stored for use.

It is also pumped, as needed, to the second tank, which stands beside the sewage tank on the roof of the pump-house. Thence it is piped to the various points in the Park and used for sprinkling the roads and lawns, and neighbouring residence avenues flushing water-closets, urinals, etc. It is clean, wholesome water, and, save for sentimental reasons, might well be used in the lavatories, restaurant, and drinking fountains.

"In all processes of bacterial oxidation the maximum efficiency is reached only after a certain period of use. The organisms which consume the impurities must be given time to multiply and spread, until their colonies are adapted to the work they are called upon to perform. The plant at Willow Grove first received sewage on May 31st (1897). The liquid was clarified immediately by the mechanical removal of suspended matters in the strainer; but its subsequent passage through the aerators caused no perceptible improvement till June 3rd, when the cloudiness and the odour began to diminish. On June 6th the effluent was entirely without odour, but was still slightly opalescent. On June 11th it was perfectly clear, colourless, odourless, and tasteless, and a sample drawn on that day has remained unchanged to this date (February 1st, 1898). This delay of maximum effect is found only on the first charging of the beds when new, the operation thereafter being continuous. Throughout the entire season the plant has worked smoothly and well, save that on one occasion the strainers became choked with a mixture of clay (which probably entered, with ground water, through leaks in the sewers) and grease—the accumulation of months in a large grease-trap at the Casino restaurant, which was emptied, with more energy than discretion, by breaking a hole in the protecting trap of the overflow, and sending the entire contents *en masse* into the collecting well. Had this grease been delivered with the sewage day by day, as made, the filters would have disposed of it without difficulty. The trouble was remedied by forking over the stone and washing it.

"The conditions at Willow Grove were, in some respects, peculiarly trying. Not only was the sewage of abnormal strength, as has been explained, but the volume varied enormously from day to day. In a town or city the domestic wastes remain practically constant in all seasons; but a pleasure park, which is crowded on a hot clear day, will be practically deserted in cold wet weather. The daily attendance at Willow Grove varied from perhaps one hundred to thirty thousand. This caused great irregularity in the operation of the sewage disposal works, and, under the circumstances, it is somewhat surprising that the result should have proved so uniformly satisfactory.

"As has been shown, the process of bacterial oxidation in artificially aerated filters is identical, in theory, with that of irrigation. The difference between them is this, that artificial aeration supplies to the entire mass of filtering material the conditions necessary for purification, which, in the case of irrigation, are confined to the surface alone. In other words, the introduction of air under pressure makes it possible to concentrate, in cubical form, in a single small bed, the effective area of a whole acre of irrigation field.

"The management of the plant is simple, and can be learned easily by an intelligent labourer. It consists mainly in judicious distribution of sewage and air, and the occasional raking over of the filter-beds. One man can care for a large plant. Where sewage can flow to the filters by gravity, the wages of the attendant and the cost of running the fan are the only expenses of maintenance. The filters once built and filled are practically indestructible and self-cleansing.

"In respect of cost of operation the method of forced bacterial oxidation allows of no comparison with any other method of sewage disposal, save only the ordinary gravity discharge into river or tideway, or over irrigation fields.

"Sewage disposal plants of the same designs are now under construction in Brooklyn, L.I., and Tuxedo Park, N.J."

The Scott-Moncrieff System.—Principles underlying the System. —It is now well understood that the work of converting matter from the organic to the inorganic state is carried out principally by the life processes of microscopic organisms, each possessed of life, and that their reproduction and increase under favourable conditions is so great as to be almost incalculable. It is the special function of these organisms to break down effete organic matter so that it may become food for plants. In this way they complete the circle of life by preparing food for vegetation, which in its turn becomes the food of animals.

In the light of these facts, there is no reason why the effete organic matter contained in ordinary sewage should be treated differently from other similar substances in nature, and it only remained to devise the means by which these natural processes could be concentrated and controlled with this end in view. The operations of the farmer afford a daily illustration of how the process is carried out upon the surface of the land.

The Classification of Organisms which Purify Sewage.—The two principal classifications of organisms in relation to their capacity for breaking up organic matter are :—

1. Those that do, and those that do not, liquefy gelatine.

2. Those that live in the presence of oxygen, and those that live without it.

The first two classes are named liquefying and non-liquefying organisms.

The second two classes were named by Pasteur aërobic and anaërobic.

Their Capacity to Carry on the Work of Purification.—If the amount of the organic matter contained in the sewage of a large town seems to be in excess of the capacity of these natural forces to deal with, that difficulty disappears in the light of the prodigious and almost incredible capacity of these organisms to increase in numbers and to consume any amount of food which could possibly be supplied to them. Mr. Scott-Moncrieff claims to be the first to recognize that the whole of the organic matter in sewage could be dealt with by micro-organisms without the aid of any previous deposition or removal which deprives them of the food it is their natural function to consume.

The Latest Developments of the System.—By the apparatus now used in the Scott-Moncrieff process the following sequence of changes is effected :—

The sewage is first brought in its crude condition, without any previous deposition, and containing all its organic matter both in solution and in suspension, into the bottom of a tank, through a long restricting chamber, which is covered by an open grating. Upon this grating are superimposed the flints or other cultivation surfaces. The incoming sewage passes by its natural flow upwards through the tank and its contents, and discharges about the same level as the intake.

It would naturally be expected that the more solid portions of the sewage, which have been found in practice so difficult to deal with, either upon land or in the form of sludge, would very soon clog and choke the interstices of the flints or other cultivation surfaces. Such is not the case, as the liquefying work performed by the organisms is so complete that the same bed goes on working for years without any trouble or attention of any kind.

After Liquefaction takes place.—It is found after liquefaction has taken place that other changes have occurred, due, first, to the action of the mixed organisms which come in from the sewage, and use up the available oxygen in the lower zones or layers of the tank ; and, second, from the work of the anaërobic varieties, which work for the most part in the zone where the oxygen has disappeared. The most prominent chemical change which takes place is the conversion of various nitrogenous substances into the simpler form of nitrogen as free ammonia.

In order to carry on this process to the fullest capacity of the anaërobic organisms, the effluent from the first cultivation tank is next passed through a chamber partly filled with inverted open-mouthed vessels, each of which forms an anaërobic cell in itself, and the effluent from this chamber is then discharged intermittently over a series of superimposed filters, each of which naturally contains a survival of organisms best suited to its own food supply, so that a complete series of organic changes is available for any desired degree of purification.

The following results (Table 92) were obtained from three series of experiments :—

TABLE 92.—PARTS PER 100,000.

	I.		II.		III.	
	0.	9.	0.	9.	0.	9.
Chlorine	9·0	7·5	6·3	6·4	5·5	5·5
Ammonia	11·5	0·25	4·25	0·755	4·0	0·42
Albuminoid ammonia	1·5	0·60	2·93	0·475	1·472	0·107
Nitric nitrogen	0·12	9·0	none	5·98	none	4·34
Nitrous nitrogen	none	slight trace	none	0·06	none	0·034
Total unoxidized N.	12·35	0·60	6·60	1·12	5·35	0·148
Organic N.	2·05	0·394	3·10	0·50	2·06	0·113
Total nitrogen	12·47	9·60	6·60	7·16	5·35	4·522
Oxygen consumed	9·84	0·589	9·05	0·608	7·52	0·632

PERCENTAGE PURIFICATION.

	I.	II.	III.
(1) Oxygen consumed	94	93·3	91·6
	AVERAGE 93.		
	I.	II.	III.
(2) Oxidation of nitrogen	93·7	84·3	96·7
	AVERAGE 91·6.		

The columns marked "0" show the composition of the unoxidized sewage after the changes resulting in the solution of the suspended organic matter have been effected in a cultivation tank. The columns marked "9" show the final filtrate as it issues from the lower bacterial tray.

It will be noticed that while the percentage of purification is very high, judged from any standard, the point of greatest interest is the ratio of the oxidized to the unoxidized constituents, and it will be generally admitted that an average production of 6·44 parts per 100,000 of nitric nitrogen by a purely natural process throws a new light on the capacities of the system as a whole, and places the effluent above suspicion wherever it may be discharged.

CHAPTER XV.

DISPOSAL OF HOUSE REFUSE AND SLUDGE.

House Refuse.—Under the head of house refuse is defined every description of waste material which has to be dealt with by the public authorities ; it thus consists of ash-bin rubbish from the houses, shops, and market refuse, road sweepings, and excremental matter.

The *amount* of this refuse assumes very large proportions as the size of the town increases ; in the case of London the average in 1895 was 260 tons to every 1,000 inhabitants, so that for the whole city, with a population of four and three-quarter millions, the refuse would amount to a total of 1,250,000 tons to be disposed of per annum.

Under the provisions of the Public Health Acts, sanitary authorities are legally bound " to (themselves) undertake (or contract for) the removal of house refuse . . . ," and they are given very full powers for providing for the proper and efficient collection and removal of such refuse ; and by section 30 of the Public Health (London) Act, 1891, it is provided that " Where the house refuse is not removed from any premises . . . and the occupier of the premises serves on the authority a written notice requiring the removal of such refuse . . . within forty-eight hours after service, and the authority fail without reasonable cause to comply therewith, they shall be liable to a fine not exceeding twenty pounds."

A carefully arranged system for the periodical and regular collection of house refuse is therefore most essential ; and in order to make it efficient fixed receptacles for the reception of house refuse should be done away with, and portable galvanized iron buckets with covers substituted. The London County Council's bye-laws provide for " one or more movable receptacles sufficient to contain the house refuse for a period not exceeding one week," and in addition they specify that the receptacles " shall be of metal provided with a cover, the capacity of each not to exceed two cubic feet." The collection, as far as practicable, should be made daily.

Collection of House Refuse.—The following averages of replies obtained to questions put by Mr. Price, then surveyor to the Local Board of Toxteth Park, to a number of towns with reference to the collection and disposal of house refuse are given by Mr. H. P. Boulnois :—Out of 85 towns from which replies were received, 70 employed their own staff for the collection of the refuse, 2 employed a contractor in addition for a portion of the work, and only 13 were dependent entirely upon contractors. The average number of carts, etc., employed per acre of the area of town worked out to ·006, but it was not stated whether the acreage given corresponded with that scavenged.

The periods of collection varied from "part daily and part once a week" to as much as once in six months.

Dr. Young's Reports on Collection and Disposal of House Refuse in London.*

Inquiry has recently been made throughout the county into the methods in force in each sanitary district for the collection and disposal of house refuse. The information contained in this report has been obtained with the aid of the local medical officers of health and surveyors, and by inspection of the various wharves and dust depôts.

(*a.*) *Collection of Refuse.*—The collection of the refuse from houses is carried out either by the sanitary authority itself—that is to say, the authority employ men, and have provided the necessary plant for the purpose, or else by contract. At the time of inquiry it was ascertained that—

In 25 districts the collection was performed by the sanitary authority ;

In 3 districts partly by the sanitary authority and partly by contract ; and

In 14 districts by contractors.

The following system has been adopted for facilitating the collection at regular intervals throughout most of the districts. Each district has been sub-divided into areas, each of which is visited by the dustmen and carts on a specified day once a week, and in some cases twice a week, for the purpose of collecting the house refuse. In some districts it is a part of the system to make a house-to-house call in order to ascertain whether the dustbin requires to be emptied, but in others no call is made unless some indication to this effect is given by the occupiers, either by placing a card bearing the letter D in the window, by hailing the dustman as he drives down the street, or by arrangement with the sanitary authority that a call shall be made at the house on a specified day, either once or more often during the week.

In some of the districts, chiefly those situated in the central parts of the county, it is stated that owing to the varying class of property and the existence of business premises, it has been found necessary to have a daily removal in some streets, and a removal once, twice, or thrice a week in others, rendering the same frequency of collection for the whole district, or a division of the district an impracticability.

As the result of the inquiry it does, however, appear to be necessary in order to ensure a regular weekly collection of the house refuse from all premises, that in those parts of a district in which a daily collection is not in force a call should be made at every house once a week, either by an inspector of the authority or by the dustman while on his round.

* Made to the London County Council, 22nd October, 1894.

The collection of the refuse is generally made in carts or vans provided with some form of cover. Tarpaulins are most generally in use for the purpose, but in some districts carts with flaps or patent covers are used.

(*b.*) *Disposal of Refuse.*—In Appendix I. attached to the report to the council by the engineer and medical officer of health on dust destructors, particulars are briefly given of the different methods of disposal of the house refuse collected in each of the London sanitary districts.

The methods in force at the date of that report, and also at the time of this inquiry, were—

(1.) Immediate removal from the district by barge or rail, or by both barge and rail without previous manipulation.

(2.) Sorting and sifting of the refuse by machinery, or by hand-labour, prior to removal by barge and rail.

(3.) Removal to shoots.

(4.) Burning in a destructor.

(1.) The first method has been adopted in the following districts—

Fulham.	Chelsea.	Kensington.
Hammersmith.	Bermondsey.	St. Pancras.
The Strand.	Greenwich.	Shoreditch.
St. Martin-in-the-Fields.	Wandsworth (partly).	St. Saviour.
Shoreditch.	Islington.	St. George-the-Martyr.
Westminster.	Camberwell.	Lambeth.

St. George, Hanover-square (part of the refuse).

St. James, Westminster (part of the refuse).

In all these cases the house refuse is conveyed by the dust cart, as soon as this is loaded, to a wharf or railway siding, and there the refuse is either shot or loaded direct into barges and railway trucks for removal to various parts of the country without undergoing any manipulation. The refuse which is loaded into the railway trucks during the day is invariably removed at the end of that day. At wharves situated on the river, the movements of barges depend on the tides, but the result of inquiries made at these wharves, and also at those on canals, show that in practice the house refuse is brought into the wharf, loaded into barges, and removed within twenty-four hours. Removal by barge is, however, subject to interruption at times, owing to the occurrence of fog, ice, or neap tides, and it may then be necessary to deposit the house refuse on the wharf temporarily for a longer period than twenty-four hours.

(2.) The second method, namely, sorting and sifting of the refuse into its constituent parts, at depôts situated in London, is adopted in connection with the house refuse collected in the following districts—

(*a.*) By machinery—

Paddington.
St. George, Hanover-square (part of the refuse).
St. James (part of the refuse).
Marylebone.

(*b.*) By hand labour—

Hackney (part of the refuse).
St. Giles } It was stated by the contractor that part of the refuse from
Holborn } these districts is at times sent away by barge at once.

Clerkenwell.	Bethnal-green (partly).	Limehouse.
St. Luke.	St. George-in-the-East.	Mile-end Old-town.
Poplar (partly).	St. Olave.	

Newington (at certain periods of the year when there is much demand for ashes and breeze by brickmakers).

Sorting by machinery is carried on at the dust depôts belonging to the Vestry of

Paddington, and to Messrs. Hobbs and Messrs. Mead. They are all situated on the north side of Paddington-basin on the Grand Junction Canal, and it was stated at each that usually the refuse brought in during the day is sorted and sifted and removed from the wharf within twenty-four hours of its arrival. The ashes and breeze are conveyed along shoots direct from the sorting machine, and loaded into barges alongside the wharf. The soft core is collected and either burnt in a furnace or loaded into barges and removed.

The condition of these depôts on the days when they were visited confirm the statements that this process of sorting by machinery can, generally speaking, be carried on without infringement of the bye-law which limits the time during which deposited house refuse in course of removal may remain in proximity to occupied buildings, streets, etc. But at the wharf belonging to the Vestry of Paddington and at that of Messrs. Mead & Co., collections of fine ash were observed, and in both cases it was also stated that these accumulations had lain there for a longer period than twenty-four hours ; it is also stated that during hot weather this fine ash is liable to become offensive owing to the presence of small quantities of vegetable refuse which are not separated by the machine.

The details of the business of hand sorting and sifting have already been described in the report of the engineer and medical officer on dust destructors. This process doubtless can also be so carried on that the house refuse is manipulated and loaded into barges within twenty-four hours of arrival at the dust-yard. But it may be said that the business of hand or machine sorting, in itself, may at times be a cause of delay in the prompt removal of the refuse or of some of its constituent parts.

Great difficulties have been encountered in solving the problem of the efficient disposal of this waste product of civilization.

In some places where waste ground has been taken up on which to deposit it, the process of putrefaction soon creates a nuisance in the neighbourhood, and it is also at the same time a menace to health ; suitable sites are also getting rarer, so that this method cannot last long. Tipping into the sea is also open to grave objections, as the foreshore in the neighbourhood soon becomes in an unsanitary condition ; it can also only be attempted by towns on the sea coast, and is thus of limited application ; the same remark applies to removing the refuse in barges and dumping it out at sea ; here also nuisances are created, and damage to fishing grounds is often involved. Complaints of this nature have recently been made in connection with the refuse disposal of Liverpool, although the barges discharge twenty-six miles out to sea.

It has been attempted to use it as a manure, but for this purpose it has to remain stacked on the farm sometimes for months until it is wanted ; in the meantime the invariable putrefaction sets in, creating a nuisance and a positive danger to health ; again, efforts have been made to manufacture it by various processes into a manure, but without any appreciable success. According to Mr. Boulnois, the returns from eighty-one towns show that thirty-five of them destroy their refuse by fire.

There is considerable room for improvement in this country in the design of the carts for collecting refuse as well as in the usual receptacles used in the different households ; the latter are as a rule most unsanitary, and allow their contents to be scattered by the wind, the dustman scatters the contents through the air into a cart, which is seldom covered or dust-tight. Mr. Kinsbruner, of Berlin, has invented an anti-dust apparatus, involving the use of special dust-bins and carts. If there is any difficulty in the general supply of "anti-dust" bins to householders, the system could still be adopted in a less perfect form by the municipality providing each van with a patent ash-bin, which could be taken into the house yard to receive the contents of the ordinary house receptacle. The apparatus in question "has been adopted and amply tested by the Imperial German Board of Health, the Royal Ministerial, Military and Board of Works Commission of Berlin, the Board of Directors of Government Railways, the Royal Charité (the largest Government hospital of that city), and many other public and private bodies." A full description is given in *The Surveyor* of January 8th, 1897, where it is stated that "a specimen van, which is in the possession of Mr. George Jennings, of Lambeth Palace Road, London, can now be seen by anyone interested."

Cost of Removal.—The cost of removal from the different districts in London by barges to the shoot is considerable, varying from 1*s.* 11*d.* to 2*s.* 9*d.* per load, shot into the barges ; in the provinces the cost is less, and varies from 6*d.* to 1*s.* 10*d.* per ton ; in the case of Manchester it amounts to 1*d.* per ton per mile by water and rail.

Mechanical Sorting.—A process for the disposal of house refuse by sorting was until recently carried out by a company, under the title of the "Refuse Disposal Company, Limited." The works were situated at the Salopian Wharf, Chelsea, and the whole of the work was done under cover, and mainly by the aid of machinery. By means of exhaust fans, all flying particles of dust evolved in the process of turning over were drawn into the furnace draughts, and so prevented from becoming a nuisance to the neighbourhood, or a danger to the dust sorters.

The process to a great extent was experimental, and only treated about 35 loads a day ; no accumulation was allowed to take place, the refuse being dealt with as brought to the works.

The following is an abridged description from a report on the process by Sir Douglas Galton :—

The principal part of the machinery consisted of three revolving cylinders, A, B and C, supported on friction wheels and driven by external gear.

The refuse was tipped direct into cylinder A from the dust carts. This first cylinder was 10 feet in diameter and 12 feet long, and had a tilt of about 9 inches in its length; it was made of iron ribs placed about 10 inches apart, upon which were fixed wooden bars, between each of which was an opening of $2\frac{1}{2}$ inches wide, so that anything less than 10 inches by $2\frac{1}{2}$ inches would pass through.

The material which passed through the meshes of cylinder A passed into cylinder B, also made of iron, 8 feet in diameter, 6 feet long, and covered with wire-work, having a mesh of $1\frac{1}{4}$ inch square. The material which dropped through these meshes was in its turn delivered by an endless band into a third iron cylinder C, 6 feet in diameter and 15 feet long, covered with wire-work, having a mesh of three-eighths of an inch.

The material which passed through the entire length of the cylinders A and B, and not through the meshes was hand-sorted, as shown in the typographical diagram following, of which the top, beginning with the word "dust," represents the point of commencement of the process, A representing the first revolving cylinder.

DUST.

A

Everything that will pass a 3-in. mesh.

—paper for paper-making ...
—rags ,, ,, ...
—straw, for burning ... ...
—boxes, ,, ,, ...
—bags, for paper-making ...
—tins, for scrap ... ...
—{ other objects too large to pass a 3-inch mesh ...

} hand-sorted.

B

Everything that will pass a $1\frac{1}{2}$-in. mesh.

small paper and light refuse blown away for millboard making.

—bones, for manure.
—bottles, for re-use.
—glass, for melting.
—iron, for scrap.
—stones ... ...
—vegetable refuse ... ...
—animal refuse ... ...
—rubbish ... ...
—pots ... ...
—coal ... ...

} For grinding and re-mixing with dust.

C

ashes through $\frac{3}{8}$-in. mesh.

breeze through $\frac{1}{2}$-in. mesh.

manure dust.

The works were lighted by electric light, generated by the fuel obtained in these operations. The value of the sorted material as fuel was found to be one-seventh that of coal, but its heating power was much increased by washing, which removed the vegetable refuse. The sorted refuse was disposed of in a variety of ways: the ground-up material from the mill was sold as a manure, and the paper, after being dried at a high temperature, so as to remove infection, was sorted and freed from dust, and then pulped for conversion on the premises into brown paper or cardboard.

Everything seems to have been done that foresight could suggest to make the system a success both financially and from a sanitary point of view, but, as already stated, the work has been abandoned.

Disposal of Sludge.—The disposal of the sludge, obtained under many of the systems of sewage disposal already described, is always a great difficulty. Efforts have been made, in connection with the chemical processes, to utilize the sludge as manure. At Birmingham, the sludge, as produced, is simply dug into the land, a sufficient acreage having been purchased for the purpose.

In the case of the metropolitan sewage, the sludge is pumped into sludge vessels, each capable of conveying 1,000 tons, and discharged in "the Barrow Deep, commencing at a point ten miles east of the Nore, and proceeding thence from five to ten miles down that channel." Although about 10,000,000 tons of sludge have thus been deposited at this point, the channel is totally unaffected, and the surface of the sand-banks is as clean as in 1888. Mr. Dibdin considers this to be due to the animal and vegetable *débris* being rapidly consumed by the organic life in the sea water.

A similar plan is adopted for the disposal of sludge by the Corporation of Salford, and quite recently by the Corporation of the city of Manchester.

The best method of utilizing the sludge is by separating the liquid from the solid matter, so as to reduce the bulk as much as possible. It is essential that this be done early, to prevent the sediment fermenting, and thus spoiling the purity of the effluent. Generally, a few hours' rest will be sufficient to ensure perfect settlement; the water should then be run off quietly to about the level of the deposit. The deposit, or mud, thus formed is drawn off into suitable receptacles for further treatment and conversion into a portable manure. There are three methods of dealing with the sludge in addition to those already enumerated, viz.:—

(a.) By evaporation.
(b.) By mechanical treatment.
(c.) By destruction.

(a.) **Evaporation.**—This may be done in dry climates, where the soil is porous, *e.g.*, sandy, by forming large shallow reservoirs with earth bottoms and sides, or by the use of tanks. The moisture is given off by evaporation, but in the former case chiefly by absorption, into the soil below, and the bulk is reduced to 20 per cent.

Such a method should not be adopted in England, as the sludge would not dry for months, and would soon become a nuisance.

Evaporation by artificial heat has also been tried; it is carried out

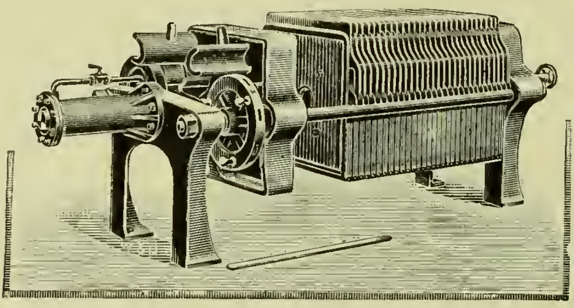


FIG. 518.—Manlove, Alliott & Co.'s Filter Press.

with either Borwick's, Forrest's, Haresceugh, or King's machines. The third is in use at Rochdale, the two former are in use in Manchester. It is, however, said to be expensive in both labour and fuel, and there is a liability of nuisance through offensive odours. It is desirable, also, that before heat is applied the filter press should be employed.

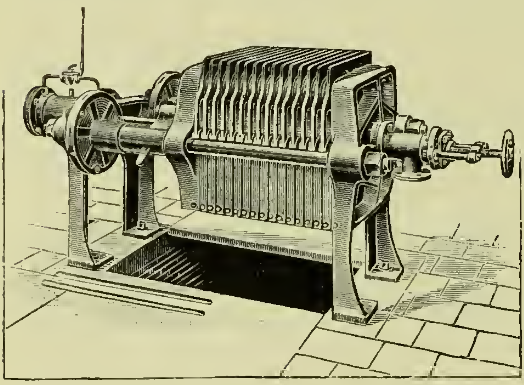
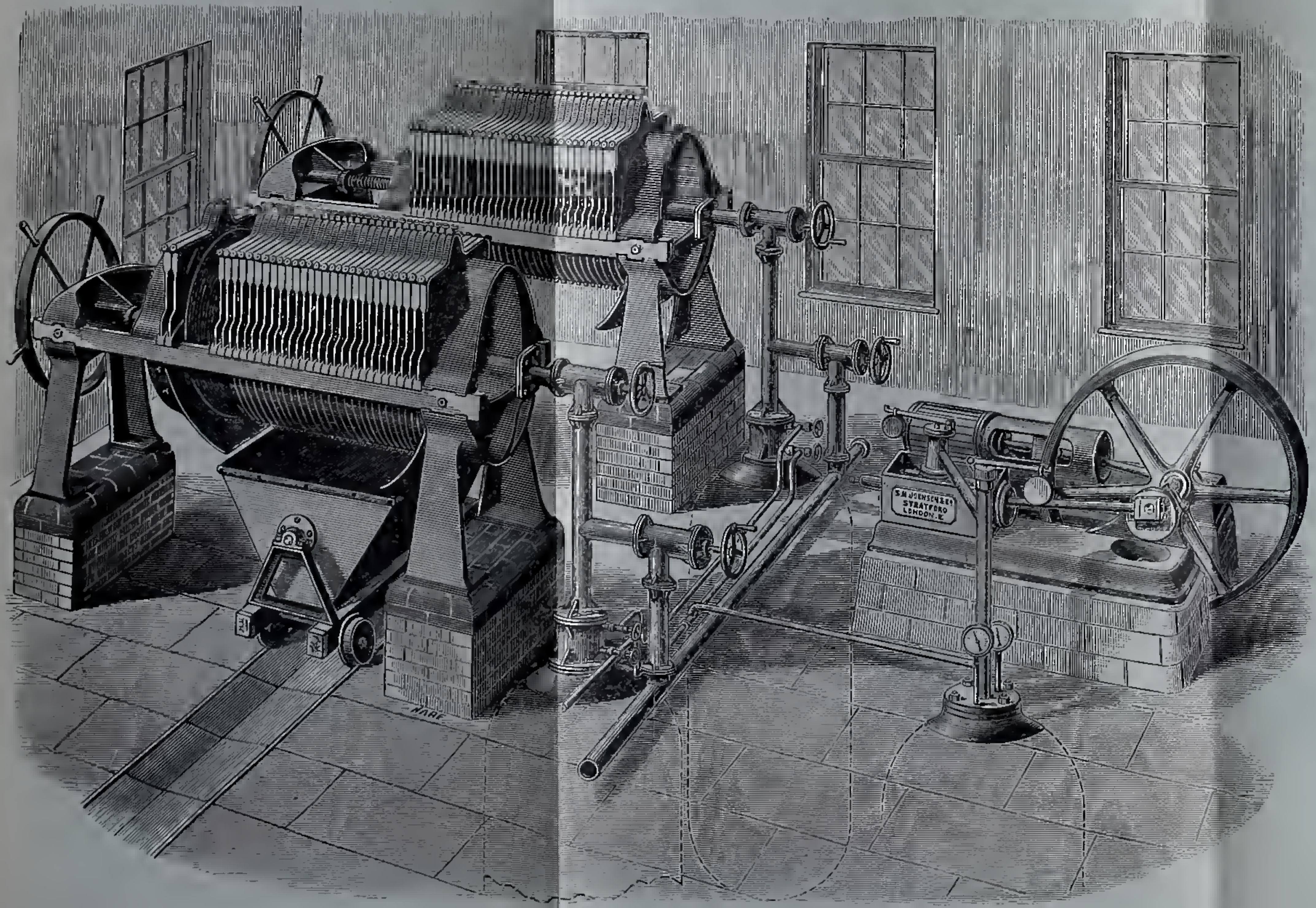


FIG. 519.—Manlove, Alliott & Co.'s Filter Press.

(b.) **Mechanical treatment** is that by means of filter presses (see Johnson's patent sludge press as shown in Plate L., and another pattern by Manlove, Alliott & Co., in Figs. 518, 519; there are many other makers). A filter press consists of a number of narrow cells held in a suitable frame, the interior faces being provided with appropriate drainage surfaces communicating with an outlet, and covered by a filtering medium, generally jute or hemp canvas, or other suitable material. The interiors of the cells so built up are in communication directly with each other, or with a common channel, for the introduction of the matter operated upon, and as nothing introduced into the cells can find an exit without passing through the cloth, the solid matter fills

SLUDGE PRESSER (MESSRS. JOHNSON & Co.). PLATE L.



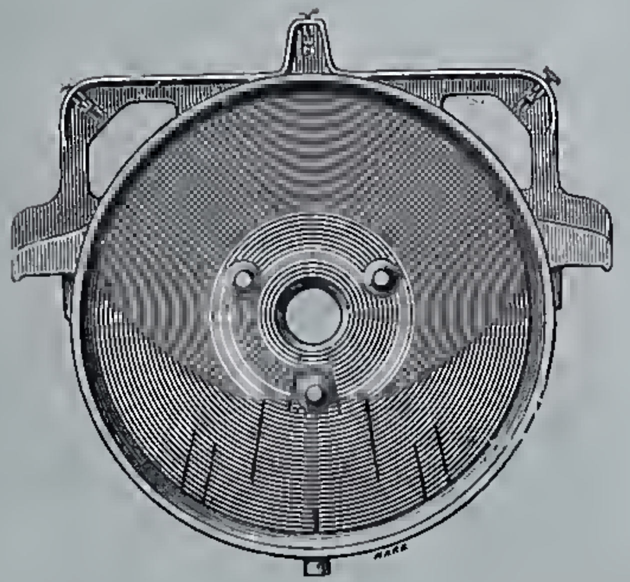


FIG I.

FIG. 2.

To face page 530.

up their interior, the liquid leaving by the drainage surfaces. The cells of the machine are subjected to pressure, which increases as the operation goes on. The cells must of necessity be made mechanically true on the outer touching surfaces, so as to prevent the material operated on escaping as the pressure increases.

An elevation of a filter press plate, and a section of three such plates as made by Johnson, are given in Plate L. They may be either circular or rectangular in shape.

The arrangement of plant by Messrs. Johnson & Co., shown in Plate L., is capable of dealing with the sludge (about 30 tons daily) from a population of 30,000, comprising the following apparatus :—Air compressor ; air accumulator ; two sludge filter presses, 3-foot diameter ; two sludge forcing vessels, with their fittings, and the various distributing pipes for sludge and air ; a tip-truck and tramway for the removal of the pressed cake discharged from the machines.

The cost of such a plant, with the requisite boiler power (about 10 horse-power actual), is about £1,000. Thirty tons of wet sludge can be easily pressed into cakes containing 50 per cent. of moisture, equalling six tons, or one-fifth of the original bulk, consisting of five charges from each machine, of 12 cwt. each, in 10 hours.

The cost of the operation, determined from actual work extending over two years at Coventry, amounts, with all expenses included, to sixpence per ton of wet sludge, or half-a-crown per ton of pressed cake.

The arrangement adopted at Wimbledon Sewage Works, by which the sludge is run off from the settling tank into the sludge reservoir, from which it gravitates into the iron receivers, each of which contains one charge, is shown in Plate LI. (facing page 538). A small quantity of lime, varying from 3½ to 5 per cent. of the volume of the sludge, is then thoroughly mixed with it, and air at a pressure of 60 lbs. per square inch is applied at the surface of the sludge, by which it is forced up the dip pipe (see Plate LI.) and into the presses, where the separation of the liquids from the solids is effected. The operation of filling the press and removing the sludge cake takes about one hour. By this arrangement every five tons of wet sludge, containing about 90 per cent. of water, can be deprived of the bulk of its moisture, giving a residue of one ton of hard-pressed cake, containing from 45 to 50 per cent. of water. The cake so obtained is easily handled, is practically inodorous, becomes air-dried rapidly, and does not again enter into fermentation. To reduce the water in the cakes, they may be loosely stacked on racks in a shed open to the wind, but secure from rain, or they may be dried upon drying floors, in kilns, or by the machines previously mentioned ; the latter process, however, increases the cost, and is not always resorted to.

Messrs. Manlove, Alliott & Company's filter press (Figs. 518, 519) is of recent design, and possesses some improvements, the chief of which is that the wheel to be worked by hand is superseded by a small cylinder, the piston of which is worked by compressed air, which it is claimed economizes time in opening and closing the press.

There are several other makers of sludge presses, such as Mr. John Wolstenholme, Messrs. Goddard, Massey & Warner, and others.

Weight of Sludge Cake.—Professor Henry Robinson has suggested the following formula to calculate the weight of sludge cake formed from a given quantity of sludge taken from the tanks :—

Let W = weight of sludge from tanks,

P = percentage of water remaining in pressed sludge,

X = weight of sludge cake.

Then $$X = \frac{10\,W}{100 - P}.$$

Sludge Manure.—The sludge, being reduced to cake, is easily transported, pulverized, and used as manure, whereas in its original state it is a material which cannot be stored, nor conveniently removed by farmers who may be willing to take it.

The value of the sludge cakes as manure will, of course, depend directly on the quality of the sewage, and the nature of the chemicals used for precipitating. Several authorities state that sludge cake gives about the same results as ordinary farmyard manure.

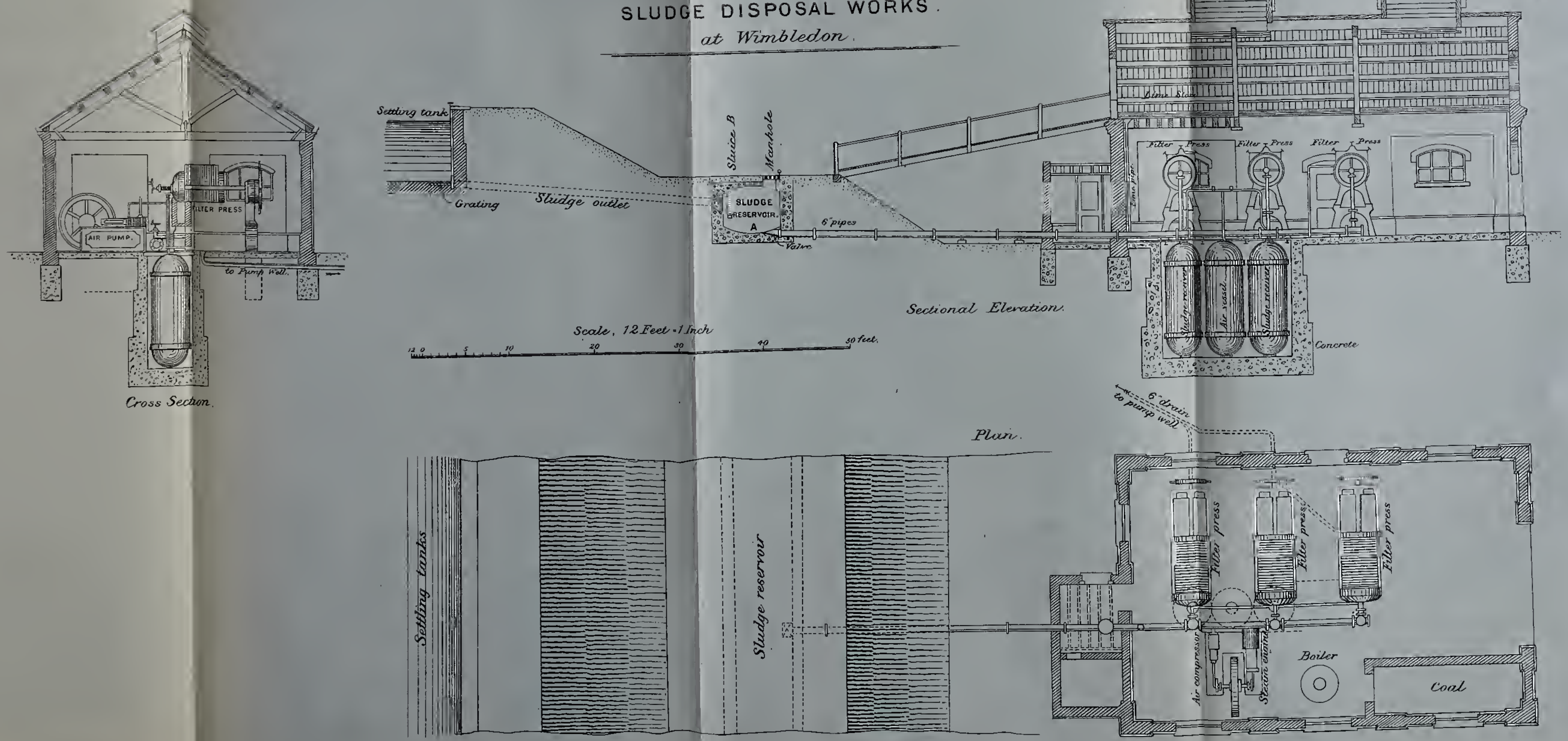
At Southampton the road sweepings are mixed with the sludge by means of a "mixer," invented by Mr. W. B. G. Bennett, C.E., the borough engineer, so as to form a portable manure. "The machine consists of a horizontal shaft, with blades somewhat like the fans of a ship's screw propeller, which, while mixing, gradually works the material out through a hole to the right into a vault, from which it can be wheeled or carted away with ease. The mixer is worked by one man. The road sweepings, before passing into it, fall on to a gridiron. Here pieces of paper and other rubbish are arrested and cleared away by the attendant. The sludge flows into the mixer direct, but it is perfectly under control, and the quantity can be easily regulated according to requirements. In wet weather ashes from the destructor furnaces are used instead of road sweepings. The mixer turns out an average of forty loads in ten hours, which is sold at from 2*s.* 6*d.* to 3*s.* per load ; while by an ingenious process some of it is made into briquettes, which, placed on garden lawns, or in other positions, there dissolve, and a manure is obtained without dirt, inconvenience, or trouble. These are sold at 5*s.* per load."*

* *Southampton Times*, March 10th, 1888.

PLATE LI.

SLUDGE DISPOSAL WORKS.

at Wimbledon.



J. Akerman Photo litho. London.

The experience of most places, however, is not so favourable, and at present there is not a very large demand for this class of manure, and it is fast becoming recognized that sludge is an enemy to be disposed of in the cheapest way possible.

Even the sludge, therefore, cannot be relied on to yield a profit on the outlay, and consequently Systems III., IV., and V. (page 427) can only be viewed as methods for getting rid of a serious difficulty in the most economical manner attainable.

As there is so much difficulty in making any profit out of the sludge as a manure, attempts have long been made to utilize or dispose of it in other ways, amongst which may be cited the system patented by the late General Scott, R.E., by which he utilized the sludge to manufacture Portland cement in connection with the lime process. The sludge was precipitated in tanks, by adding lime and clay, afterwards dried, and finally burnt in kilns similar to those used for making ordinary Portland cement. The resulting clinker was then ground to powder. This process was carried out at Burnley, but its use has been discontinued.

At Rochdale the pail refuse is manufactured into a dry, highly-concentrated manure by the aid of the heat generated in consuming the house refuse; the ammoniated manure sells at 8*l.* per ton. The lighter and more combustible portions of the greater portion of the refuse is separated from the dust by means of a screen, and is the only fuel used in the driers in the manufacture of the manure. The balance of the house refuse over and above that required for fuel for the driers, is taken with the dust from the screen to the destructors and there burnt. The furnaces have horizontal grates, and are fed and clinkered from the front as obtains with an ordinary steam boiler furnace, and each double furnace is stated to be capable of burning 30 tons of refuse per 24 hours; the labour must, however, be greater than in those types which feed from the top. The clinker after burning amounts to 35 per cent., and is utilized for mortar-making at 4*s.* per ton, and for making concrete, tar paving, etc. The chimney stack of the furnaces is 250 feet high.

Johnson & Hutchinson's Patent Pneumatic System (Plate LII., facing page 540).—The patentees have devised a system of operating the whole of the machinery in a sewage works by means of vacuum or compressed air, and by combining an oil engine with a set of high and low-pressure compound air pumps and a vacuum pump, uniting all in a single machine. A low-pressure air service from the low-pressure air pump is employed to work the various chemical mixers for the treatment of the sewage, and the liming of the sludge on the principle of their patent pneumatic mixers. High-pressure compressed air is used not only for forcing the sludge into the sludge presses, as has hitherto been usual, but also by the employment of a vacuum arrangement they dispense with the use of sludge pumps, making use of the pneumatic forcing receivers as a substitute. The patentees claim that the transmission of power is of the simplest character, being by simple pipes and valves. There are no machine moving parts, and as a result, the wear and tear is reduced to a minimum.

(c.) **Destruction.**—Another process is that of *destruction*. Buildings called "destructors" are used for the purpose at Ealing and Southampton, as described later on in connection with the disposal of house refuse.

Destructors, General Remarks on.—The object of a destructor is to convert the putrescent or decomposing matter contained in town refuse into fixed and harmless products by means of combustion; the organic products present are thus converted into the comparatively, if not absolutely, harmless forms of water vapour, carbonic acid gas, and nitrogen, all of which are commonly found in ordinary atmospheric air. It is necessary in order to avoid a nuisance that complete combustion should be ensured, and all dust arrested before the gases escape up the chimney.

In order to effect these objects a high temperature in the furnace must be maintained, and to ensure this a strong draught is necessary, and also a well distributed supply of air to the burning fuel. The lowest temperature necessary to deodorize the noxious fumes from burning ashbin refuse is 1,350° Fahr., but a higher temperature, of not less than 2,000°, is essential so as to ensure the destruction of all disease forms, as well as that of the gases and offensive vapours given off. By this means an efficient calcination and the reduction of all refractory materials can be effected so as to produce the minimum percentage of clinker and ash, and of such a quality as will enable them to be utilized, and so not only save the expense of carting them away and tipping to waste, but actually become a source of revenue; this is a powerful argument in favour of the employment of high-temperature destructors. An average residue of about one-third of the weight of the unscreened ashbin refuse of clinker and ash is thus left, the two-thirds having been destroyed by fire.

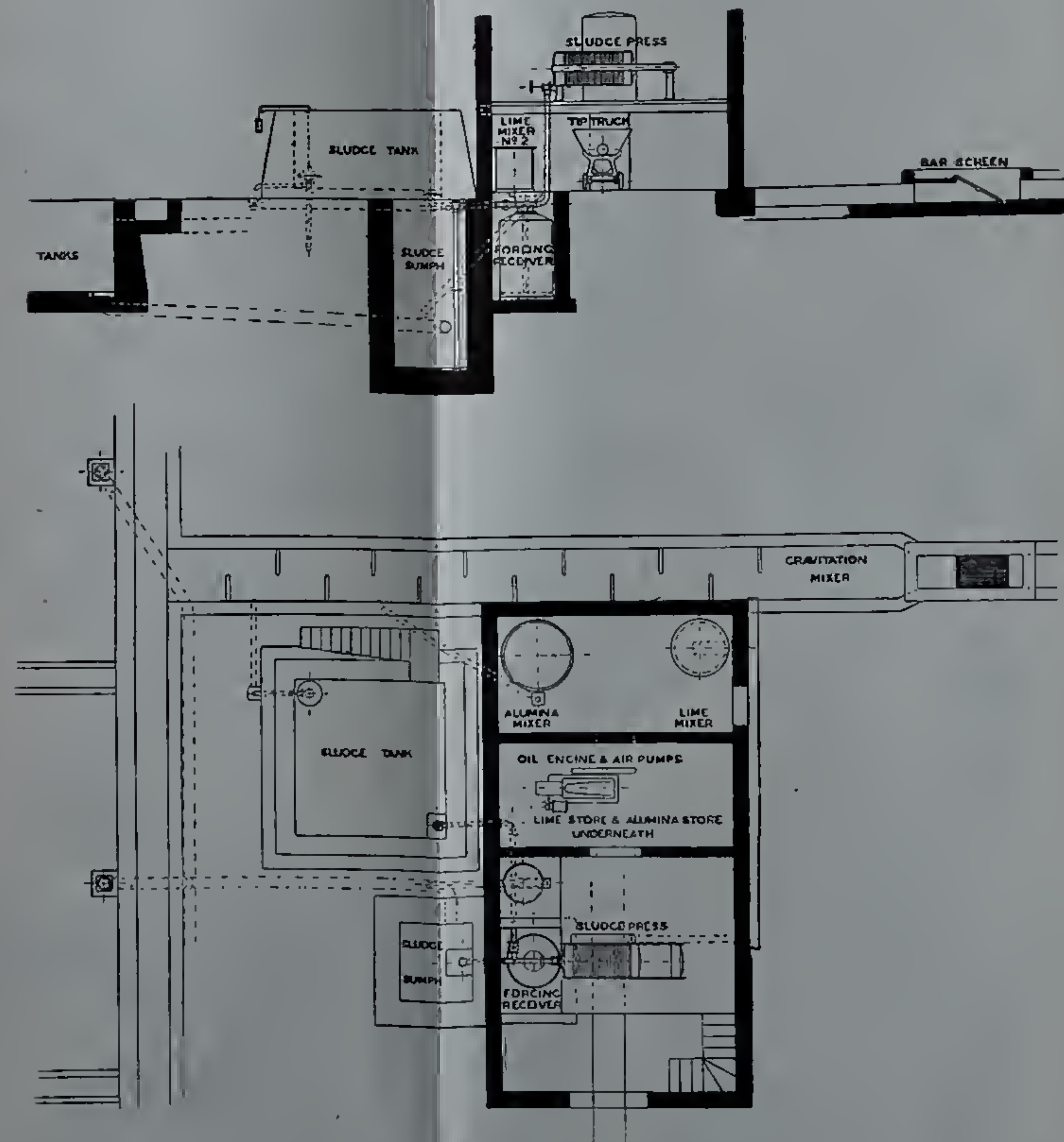
With an efficient special furnace about 6 cwts. of ashbin refuse can be burnt per hour with a good natural draught on a fire-grate 25 feet square. This may be increased to one ton per hour with a forced draught or air pressure of from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches of water.

Destructors should be so designed as to involve the least possible expense in working; the amount of handling the refuse has to undergo should be arranged so as to reduce it as far as practicable, the apparatus at the same time should not be complicated, as, in the presence of dusty and dirty material, it is sure to deteriorate very rapidly.

Plate LII.

ELEVATION AND PLAN OF SEWAGE DISPOSAL WORKS FOR A SMALL TOWN.

(Johnson & Hutchinson's Pneumatic System.)



To face page 534.

As regards the furnace itself the process should be continuous; the refuse should be fed in at one end, and clinkered at the other, in such a manner as to avoid unnecessary labour in breaking up the clinker in order to extract it through too small openings.

Cost of Construction.—Mr. Boulnois gives the average cost of construction of a destructor as 525*l.* per cell. According to Mr. Charles Jones, M.I.C.E., the cost of construction of a destructor, excluding excessive cost of foundations, but including cremator, and what may be considered as an ordinary cost for chimney shaft, ought not to exceed 400*l.* per cell. In some cases, as at Winchester, the details show the cost to have been from 200*l.* to 250*l.* per cell.

The class of destructor, the work required to be done, and the size of the town, must of necessity have an important bearing on the question of cost. The enclosure, length of sloping approach, roads, drains, erection of shaft, and engine power, should be considered separately, as they must vary considerably according to local requirements.

Cost of Destruction.—Mr. Charles Jones, M.I.C.E., in his book on "Refuse Destructors," published in 1894, gives the returns received by him from 46 towns, with 51 destructors, and as the result of his investigation that the average expense incurred varied from "3½*d.* to 1*s.* 7*d.* per ton or load—about 10*d.* being a fair average. At Ealing the cost is high in consequence of destroying the sludge, but the amount is reduced largely by allowance for clinker, etc.

"The cost of cremating the fumes, etc., varies from 1*s.* 4*d.* per ton, where only cinders are used, to 3¼*d.* per ton (at Ealing). One isolated case, where coke is used, stands as high as 7*d.* per ton."

The above is exclusive of interest or the cost of construction.

Mr. Boulnois gives the average cost of destruction of refuse as amounting to 11½*d.* per ton, the average number of men employed being 1·17 per cell. The average annual cost per cell is also estimated to be 96*l.*

Analysis of London Ashbin Refuse.—The following is an analysis of London "ashbin" refuse according to the London County Council:—

Breeze, cinders and ashes	64 per cent.
Fine dust	19 ,,
Paper, straw and organic matters	12 ,,
Bottles, bones, tin, crockery, etc.	5 ,,

The fuel value is from one-tenth to one-fifth that of good coal according to different authorities.

A small amount of coal is used on such days as there is no collection such as bank holidays and Sundays, amounting on an average to three tons per day.

The quantity of refuse obtained per year is about 22,000 tons, and the cost for burying was 3*s.* $2\frac{1}{2}$*d.* per ton, which has been reduced by the use of the destructor to 1*s.* $2\frac{1}{2}$*d.* per ton, thus effecting a saving of 2,200*l.* a year.

Utilization of Spare Heat.—Efforts are being made to utilize the spare heat obtained in the process in a variety of ways, but especially in raising steam for driving machinery and electric lighting. There is some difficulty in reconciling the proper functions of a destructor with the needs of a boiler for the production of steam, as it is essential in any arrangement for this purpose to keep the primary function of a destructor well in view, and ensure that its action in this direction is as perfect as possible; when the gases have fully performed their work in the furnace, they may then be applied to a suitable boiler, and the result taken for what it may be found to be worth. If steam power is required for pumping, electric lighting, etc., considerable economy may in many instances be effected by utilizing the surplus power available in this way. The boilers should be placed near enough to the cells to avoid any serious loss of heat by radiation, but not near enough to interfere with the perfect combustion of the gases. Water-tube boilers are apparently the best adapted for the purpose.

Professor Kennedy states, in his report on the proposed electric lighting of the borough of Ipswich, that " it is very easy to over-estimate the saving in fuel which can be effected by combining an electric light station with a destructor. Yet there is no doubt that some economy will result from the combination, and this is a point which is worth while keeping in mind."

On the other hand, as the requirements of an electric light installation are constant, it must not be dependent on the destructor, the supply of power from which may be interrupted at any moment for repairs, etc.; it should therefore be complete in itself, with arrangements for utilizing such auxiliary power where available.

In "Refuse Destructors, with Results up to Present Time,"* Mr. Charles Jones, C.E., states: " I look upon the destructor as suitable for every place, large or small, with a population of over 2,000 people. But as an electric lighting power to such a population as this it would be perfectly useless. It will be found that there are no fewer than 863 towns in England with a population of less than 25,000, but there are no less than 944 towns with a population of under 50,000, and that out of the 1,005 towns or thereabouts, which come under the direct supervision of the Local Government Board, as municipalities, local boards, or other urban sanitary authorities—omitting London and districts

* Published in 1894.

appertaining to it—there only some twelve towns with a population of over 200,000 people ; but I cannot but help thinking that so far as the value for electric lighting purposes is concerned, you can only reckon upon the towns over 25,000 population, or a total of about 142 towns.

"I do not produce these figures in any way as undervaluing any statistics that may be put forth, but when it is remembered that these statements go into the hands of a large class of persons who have no knowledge whatever of the subject other than that which they glean from such papers, I think it far better to put such a question upon what I cannot but consider a fair and indisputable basis. At the same time I would, and do, estimate at the fullest possible value the destructor as a grand *sanitary* adjunct to every town, as it may be utilized for the smaller towns included in the 863 to which I have already referred, and where five to ten H.P. may be made use of for purposes other than electric lighting.

"And here I cannot but say that looking over the various forms of destructor now before the public, that the more *simple*, the less hampered with machinery, and the more generally utilizable, the better, and certainly so far as the application of the Fume Cremator to the destructor is concerned, I consider it not only as a valuable factor in its original purpose as a fume-destroyer, but further, if utilized, especially in smaller towns, as an adjunct to the destructor for the creation of steam, it assumes a far more important character, inasmuch as it may be used, and that continuously, even when the destructor is not working ; and, bearing upon this, the engineer to the borough of Hastings informs me that the cremator just doubles the I.H.P. he obtains from destructor-cells alone."

The Shoreditch Vestry have applied the refuse of the municipality to the production of electricity for electric lighting in a very satisfactory manner.* Professor George Forbes read a paper before the National Electric Light Association at St. Louis in 1893, in which he stated : "Taking the ordinary house refuse, consisting of ashes, coal, wood, paper, old boots, vegetables, bones and scraps, crockery, tin cans, iron pots, and bottles, and adding thereto occasionally dead cats and dogs, infected mattresses and condemned meat, I can throw the whole of these, without sorting, upon the furnaces, and without producing any offensive odour or dust, I can raise the temperature of the gases, when they reach the boilers, to over 2,000° Fahrenheit. From my data as to the amount collected in different houses in England per head of population, I find that from the house refuse of any town I can supply enough steam to generate electric light at the rate of one 16-candle power lamp per head of the population for two

* *Vide* pages 583—587.

hours every night of the year. By doing this I am saving the municipality from 2,000*l*. to 4,000*l*. per annum per 100,000 inhabitants for the cost of removal of house refuse."

Power Available.—The following estimate of the power available for utilization at several destructor installations in different parts of England has been made by Mr. T. Tomlinson, B.E., A.M.I.C.E. The results are reduced to a consumption of six tons of refuse per diem of 24 hours, and are given in indicated horse-power :—

TABLE 93.

Locality.	I.H.P.	Locality.	I.H.P.
Botley	8½	Hastings	5
Birmingham	50	Hastings (with cremator)...	10
Blackburn	5½	Liverpool	4
Bury	3	Southampton	4
Ealing	4	Warrington...	8½

Mr. W. B. G. Bennett, M.I.C.E., borough engineer, Southampton, in his report to the Works Committee of 22nd February, 1898, gives the results of several tests of the power available with Worthington pumps. Table 94 is a daily return of the quantity of sewage pumped.

TABLE 94.

Date.	Time.	Quantity pumped in gallons.	Total.	Refuse burnt.
Thursday, Feb. 17	12 noon to 6 p.m.	389,206		Tons. cwt. qrs.
	6 p.m. to 6 a.m.	600,714	989,920	55 10 1
Friday, .. 18	6 a.m. to 6 p.m.	2,104,454		
	6 p.m. to 6 a.m.	651,360	2,755,814	47 14 1
Saturday, ,, 19	6 a.m. to 6 p.m.	860,936		
	6 p.m. to 6 a.m.	556,462	1,417,398	40 14 0
Sunday, ,, 20	6 a.m. to 6 p.m.	695,612		3 cwt.
	6 p.m. to 6 a.m.	547,998	1,243,610	Breeze Coal
Monday, ,, 21	6 a.m. to 6 p.m.	744,372		
	6 p.m. to 6 a.m.	720,314	1,464,686	61 7 1

"In running this test with the engines, I have also taken the opportunity to ascertain the power of the refuse destructor for working the plant, and the quantity of house refuse burnt per day is shown in the table. It will be interesting to note that on Friday, the 18th, 2,755,814 gallons were pumped in 24 hours, but of this quantity 2,104,454 gallons were pumped in 12 hours, the house refuse furnishing sufficient fuel to accomplish this ; the larger quantity dealt with on the 18th was, I am of opinion, due to an inrush of tidal water from some portion of the existing system of sewers west of Chapel Road, which I am now proceeding to locate."

At Southampton the refuse of a population of 65,325 has been found capable of running a 31·5 I.H.P. engine all the year round; a maximum of 50 tons, and a minimum of 25 tons, being burnt in 24 hours in a 6-cell Fryer destructor; the result described has been obtained by the smaller quantity in 24 hours. At Ealing 4 I.H.P. is obtained continuously, per cell burning 6 tons per day of 24 hours. The results obtainable must depend very largely on the quality of the refuse to be disposed of.

Destructors have been introduced in many large towns during the last 25 years. Manchester and Birmingham were about the first, and then Leeds, in 1877; Blackburn, Bradford, and Bury, in 1881; Bolton, Hull, Nottingham, and Salford, in 1882; Ealing, in 1883; London, in 1884; Newcastle, Preston, and Whitechapel, in 1886; and Bournemouth, Batley, Longton, and Battersea, in 1887, and later Oldham and Cambridge, whilst other towns are either erecting, or upon the point of erecting, destructors.

Two Classes of Destructors.—Destructors generally may be divided into two classes:—

(1.) The slow combustion type.

(2.) The high temperature or forced-draught furnace.

The advocates of the former class deprecate "the use of high-temperature furnaces as expensive in repairs and more costly in working, requiring more firing and clinkering, etc., while the advocates of high-temperature furnaces allege that the fierce heat and forced draught throw off particles of silica in a melting condition, which adhere to the brickwork and preserve it; and so great is the growth of this incrustation, that it has to be periodically knocked off the brickwork. At Rochdale a large heap of the incrustation has been preserved, in the hope that some special use will some day be found for it, but if nothing else, it is certainly the best possible clinker which can be produced." —*Vide the Cardiff Report*, page 603, and also page 559.

Under the first heading may be mentioned Fryer's patent destructor furnace, fitted with Jones' patent fume cremator; and as a type of the second class, the Horsfall destructor, which is provided with a steam-jet forcing draught to obtain the desired higher temperature, which is stated to be 2,000°. Destructors vary considerably in detail.

The following are a few of the high-temperature destructors also in use:—

Warner's patent "Perfectus."

The Bennett-Phythian destructor.

The Beaman & Deas patent destructor.

The Meldrum destructor.

Fryer's patent is shown in Plate LIII. It consists of a group of furnaces, or cells, lined with firebrick, and tied with iron rods; the height is about twelve feet. An incline leads from the adjoining road to a platform against, and higher than, the top of the destructor, on to which the refuse is carted, and another inclined road leads from the same adjoining road down to the level of the firing floor, by which means the products are carted away. Each cell consists of a sloping furnace, with hearth and fire-grate covered in by a reverberatory arch of firebrick, with one opening at the top for the admission of the refuse, and another opening at the side near the top for the gases to escape into the flue. A furnace frame and doors are provided for the withdrawal of the clinkers. The refuse, which is tipped from the platform on to the top of the cells, is pushed down the incline, or throat, with a long iron prong, and slides forward on to the sloping hearth, whence, when sufficiently dry, it is helped forward on to the fire bars, where it burns, the firebrick arch above concentrating the heat upon it. The opening for the entry of the refuse is divided from the opening for the exit of gases by a partition wall, with a bridge. This prevents the refuse, which is heaped up immediately below, from finding its way into the flue also. At intervals of about two and half hours the clinkers are withdrawn from the furnace doors, but the charge of refuse is maintained permanently at the top. The effect of this is that no doors are required, the charge keeping down all smoke. The result of the process is that everything is consumed, or converted either into clinkers or a fine ash. Openings with doors are provided for the introduction of infected mattresses, diseased meat, etc., on to the fire. The chimney-shaft is usually from 120 to 180 feet high.

The gases from the furnaces on the way to the chimney-shaft can be utilized by dampers, so as to pass through a multitubular boiler to generate steam, and supply an engine which works mortar-mills, etc.

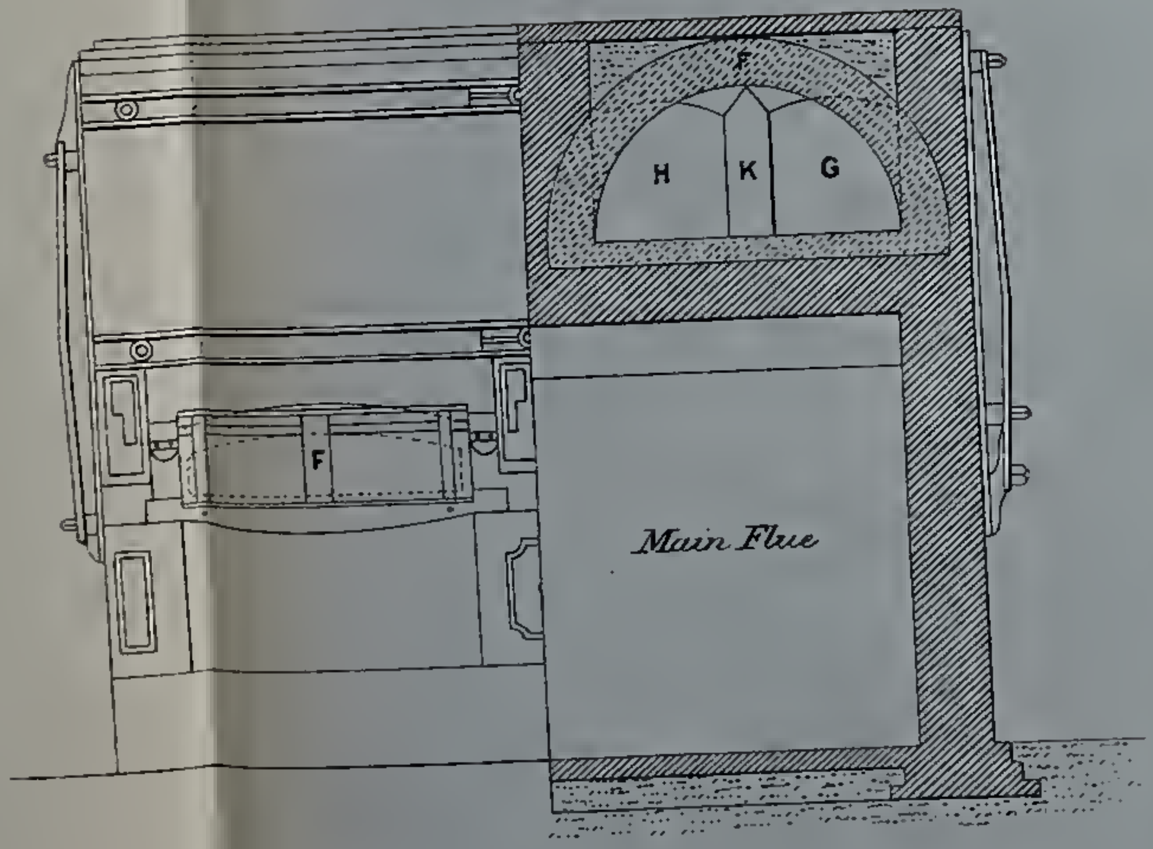
The cost of construction varies, but is on the average from 350*l.* to 700*l.* per cell.

Ealing.—At Ealing Sewage Works this destructor was developed and improved by Mr. Charles Jones, C.E., so that he is able to burn the sludge from the precipitation tanks with the aid of the refuse, without previous pressing. Mr. Jones's view is that every town produces sufficient refuse to burn the sludge, and in order to effect this he mixes the sludge with the house refuse. A very few days after the sludge has been pumped into the ash-beds (Plate LIV.) all the draining and drying necessary has taken place, and the material burns readily.

In 1887, with the aid of four cells, the destructors at Ealing dealt with the sewage sludge of a population of 19,000, and the house refuse

FRYER'S PATENT DESTRUCTOR FURNACE.

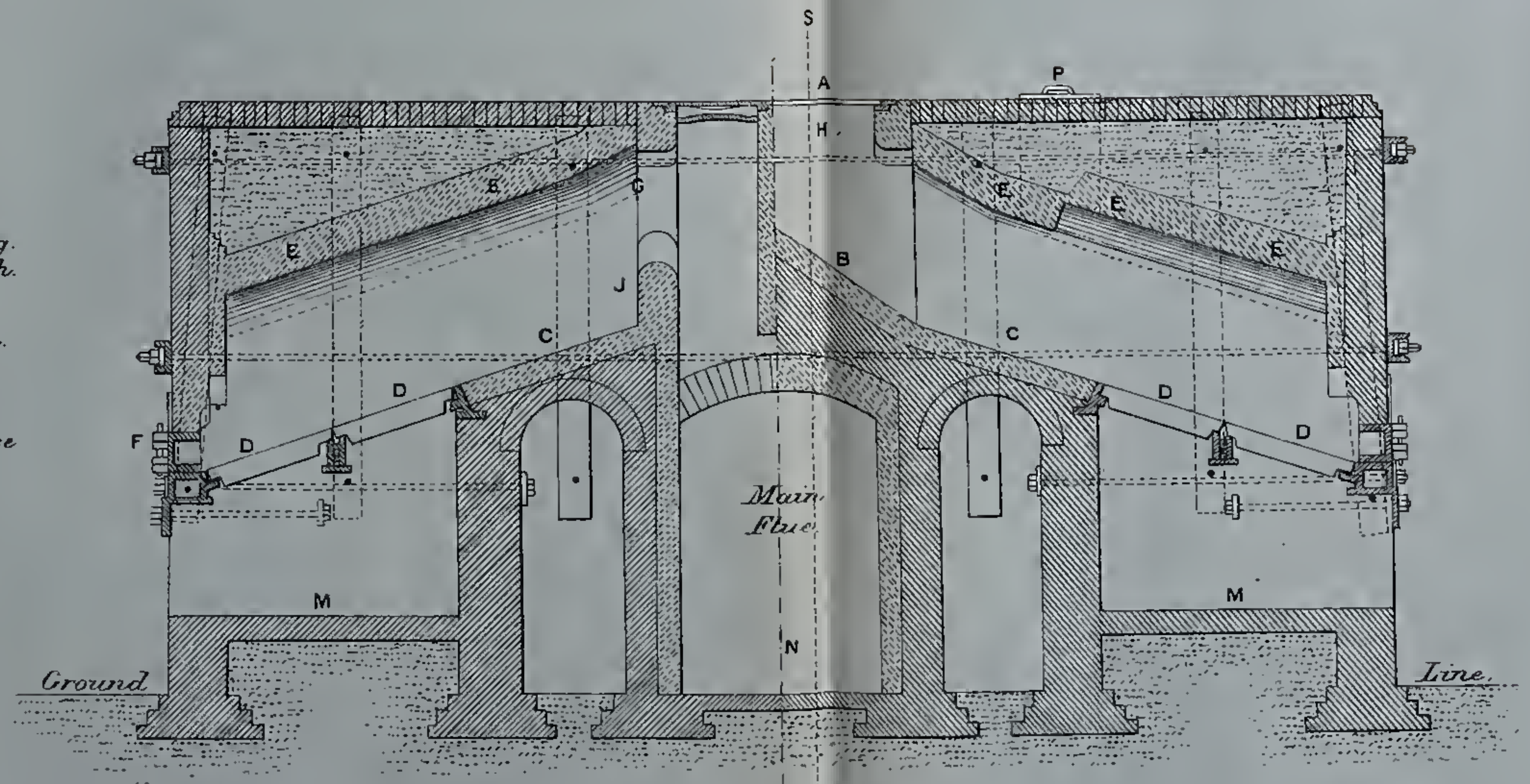
BACK TO BACK.



Half Elevation. Half Section. at SS.

REFERNCE.

A Refuse fi opening.
B Incline ' are hearth.
C Drying 'arth.
D Fire bars
E Reverberary Arch.
F Clinkeri doors.
G Opening 'gases.
H refuse.
J Bridge teep refuse out of the.
K Wall to die gases from refi
M Ash pits.
N Flue to cney.
P Mattruss ning.



Cross Section.

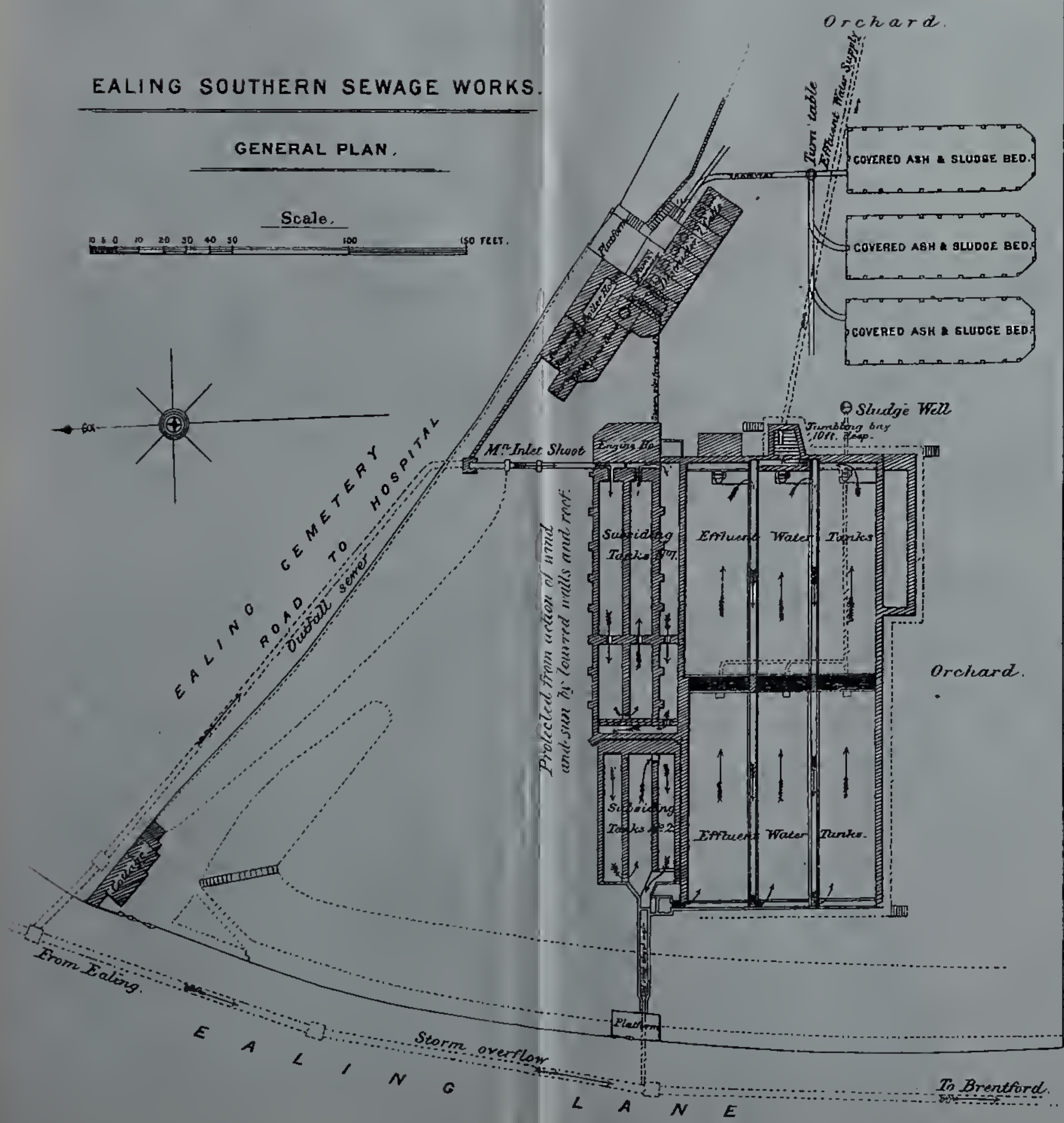
S

ale ¼ Inch = 1 Foot.

J. Akerman Photolith London

EALING SOUTHERN SEWAGE WORKS.

GENERAL PLAN.



of 22,000. It was found at first that the smoke from the chimney created a nuisance, in consequence of a certain amount of vapour given off by the fresh fuel passing into the flue without coming into contact with fire. This led to the invention of Jones's fume cremator (Plates LV. and LVI.), which consists in the introduction of a "muffle" furnace, intermediate between the cells and the main shaft. Thus everything coming from the cells, burnt or unburnt, has to pass through an intermediate furnace, producing absolute combustion. This cremator is kept going at a cost of 4*s.* 6*d.* per day, the fuel being coke-breeze, and the increased combustion gives additional steam for engine purposes, and, by accelerating the draught, assists very materially the combustion in the cells themselves. The total cost of the destructor, cremator, and chimney was about £2,000.

The report of Professor J. A. Wanklyn on the result of the system at Ealing is as follows :—

"On 9th December, 1887, I paid a visit to the Ealing (Southern) Sewage Works, where all the house refuse and nine-tenths of the sewage from the Ealing district (population, 22,000) is dealt with.

"At these works there is in operation a 4-cell 'Fryer's Destructor,' together with certain adjuncts designed by Mr. C. Jones, C.E., the engineer to the Ealing Local Board. 'Jones's Fume Cremator' especially attracted my attention. Readings of the temperature were made at the time as follows :—

In passage from cells to 'Fume Cremator'	610° Fahr.
In 'Fume Cremator'	1,270° „
After leaving 'Fume Cremator'	1,100° „

"At these temperatures, and in presence of the accompanying air, all septic poisons are destroyed, and organic compounds are resolved into carbonic acid, water, and nitrogen gas ; only the minutest traces of empyreumatic products could survive and pass away through the shaft into the general atmosphere. No harm to the health of the community is to be expected or feared from these products."

The cells more recently made are two feet three inches longer than shown in the plate, and give better results ; the single blocks (Plate LV.) are also considered better than double blocks, back to back (Plate LIII.), being more readily accessible both at back and front.

The number of cells in existence is now eight, and they consume 24 tons a day from a population of 26,500, in addition to the sewage sludge, from a population of 23,000.

The following detail of the cost of working the destructor at Ealing is taken from a paper read by Mr. C. Jones, C.E., before the Association of Municipal and Sanitary Engineers and Surveyors, at Leicester, in July, 1887.

Ealing.—Disposal of sewage sludge and house refuse, etc., for the year ending March 25th, 1887 :—

Details of Quantities and Cost.

	Tons.
Quantity of dust, house refuse, etc., received at works during the year 1886. This includes the dust tipped direct to the destructor, about two-thirds of total amount received	3,267
Quantity of sludge (after deducting 50 per cent. for moisture drained off) produced per annum from the population of the district	4,421
Total of ashes and sludge when mixed, per annum	7,688
Quantity of ditto carted away by market gardeners per annum	1,565
Net quantity of sludge and ashes to be dealt with by destructor	6,123
Annual working expenses	£230 3*s.* 10*d.*

$$\frac{£230\ 3s.\ 10d.}{6{,}123} = 9d. \text{ per ton nearly.}$$

Abstract of Expenses and Receipts.

	£	*s.*	*d.*	£	*s.*	*d.*
Labour	380	0	0			
Coke-breeze	36	8	0			
Repayment of loan and interest on prime cost of destructor, shaft, etc.	115	13	4			
				532	1	4

Credits.

	£	*s.*	*d.*	£	*s.*	*d.*
The heat from destructor and cremator gives us sufficient steam to work our machinery, thus saving six chaldrons of coke per week. £3 6*s.* per week for 52 weeks ...	171	12	0			
1,960 yards of hard clinker (25 per cent. of material put into destructor) at 1*s.*	98	0	0			
Sale of rags, bottles, etc., from dust	32	5	6			
				301	17	6
Total working expenses				532	1	4
„ saving				301	17	6
Annual working cost				£230	3	10

Gross annual expenses in connection with the treatment of sewage sludge and ashes combined :—

Labour.

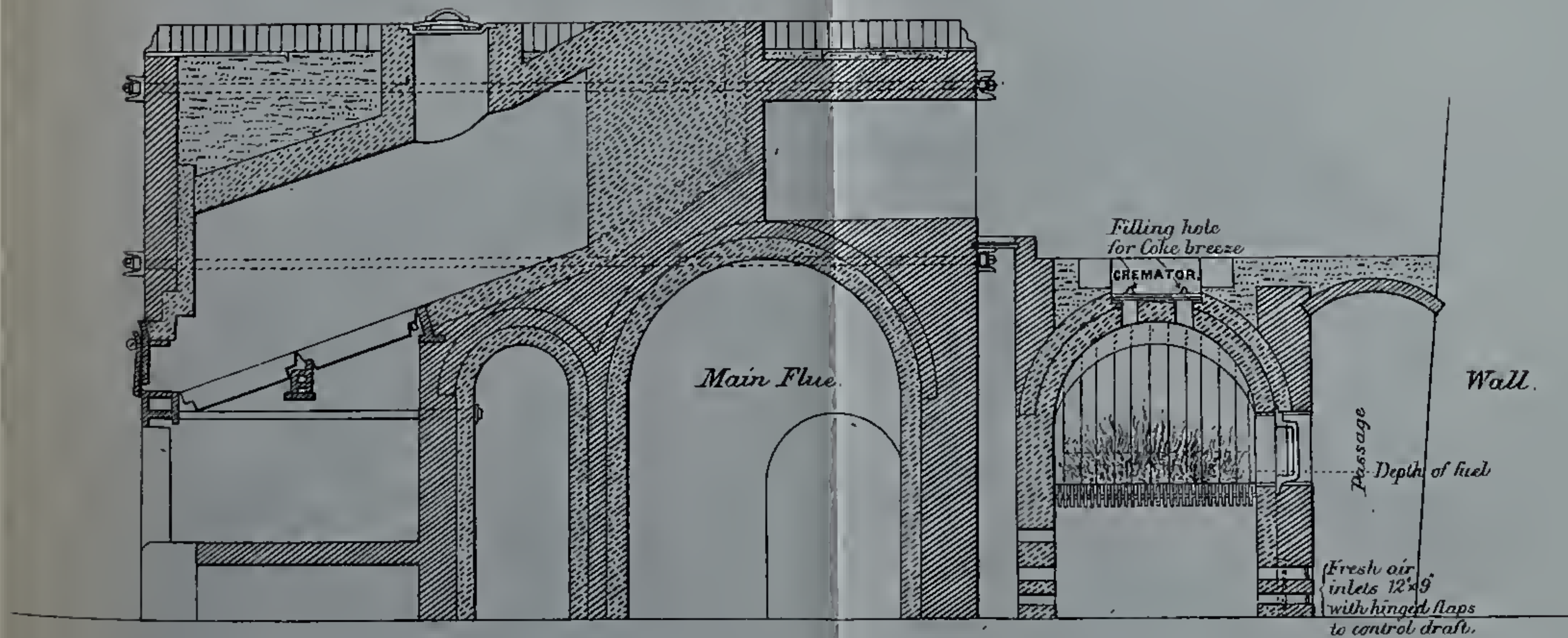
	Per Week.	£	*s.*	*d.*	£	*s.*	*d.*
3 men stoking and feeding, 2 at day and 1 at night. Total time	21 days 2 hours at 3*s.* 10*d.*	4	1	3			
1 man screening ashes	3 „ 0 „ 3*s.* 8*d.*	0	11	0			
„ „ „	3 „ 0 „ 4*s.* 2*d.*	0	12	6			
Sludge—					5	4	9
1 man loading trucks	6 „ 0 „ 3*s.* 8*d.*	1	2	0			
„ „ „	6 „ 0 „ 3*s.* 4*d.*	1	0	0			
					2	2	0
					£7	6	9

PLATE LV.

EALING DESTRUCTOR.

WITH FUME CREMATOR ATTACHED.

Section through Cell and Cremator.



Scale, 4 Feet to 1 Inch.

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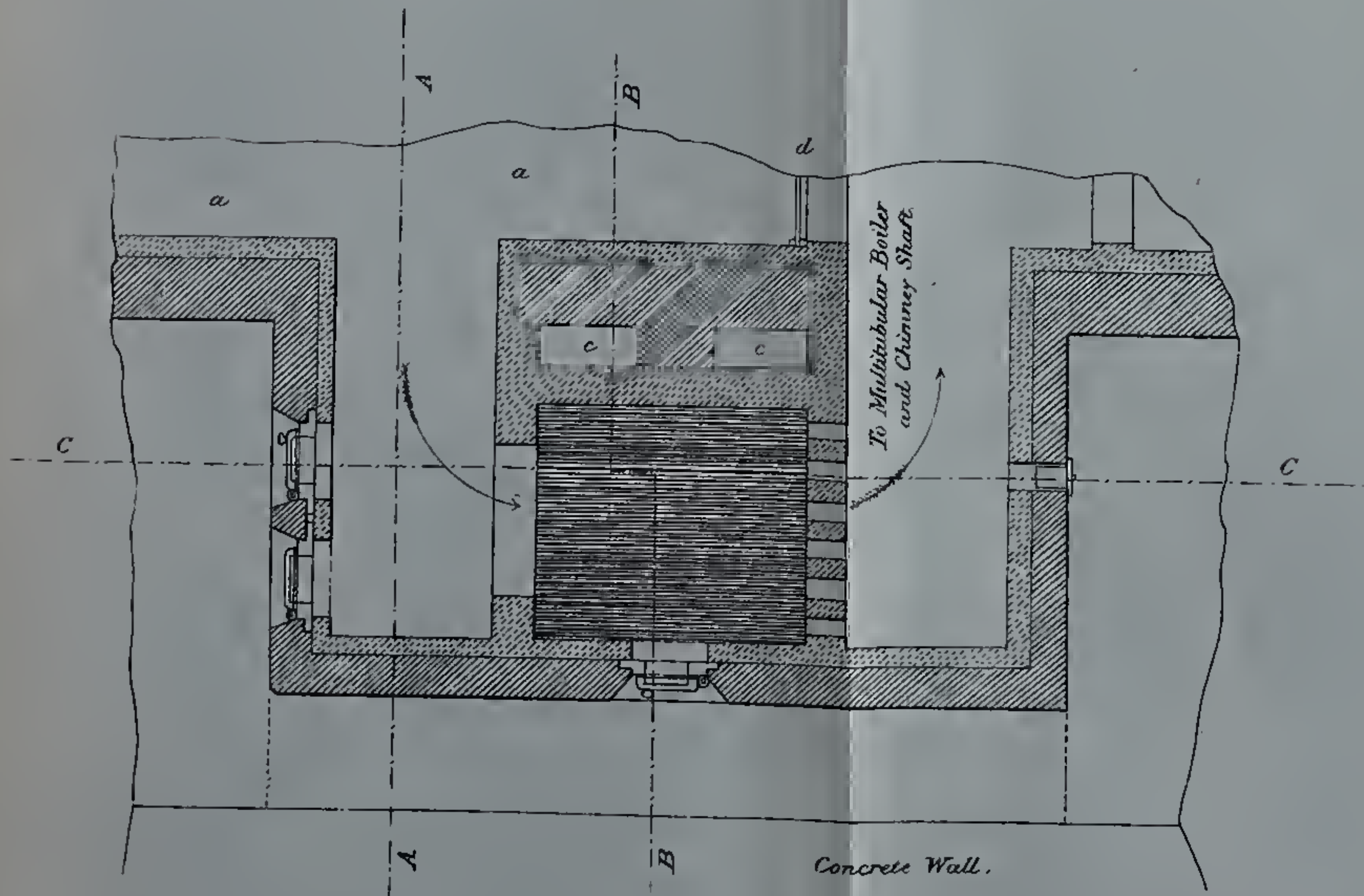
PLATE LVI.

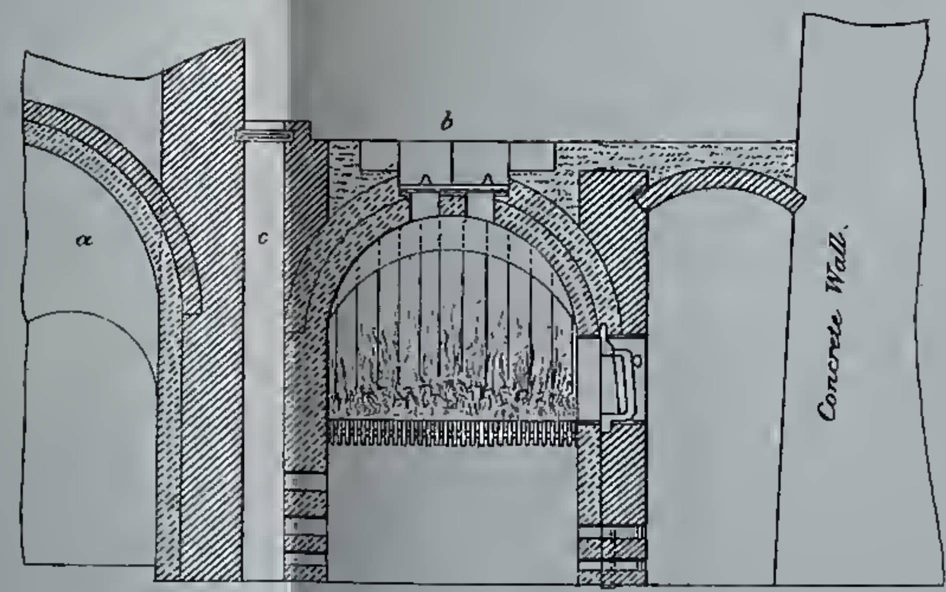
JONES'S PATENT "FUME CREMATOR".
AS IN USE AT
EALING, MIDDLESEX.

REFERENCE.

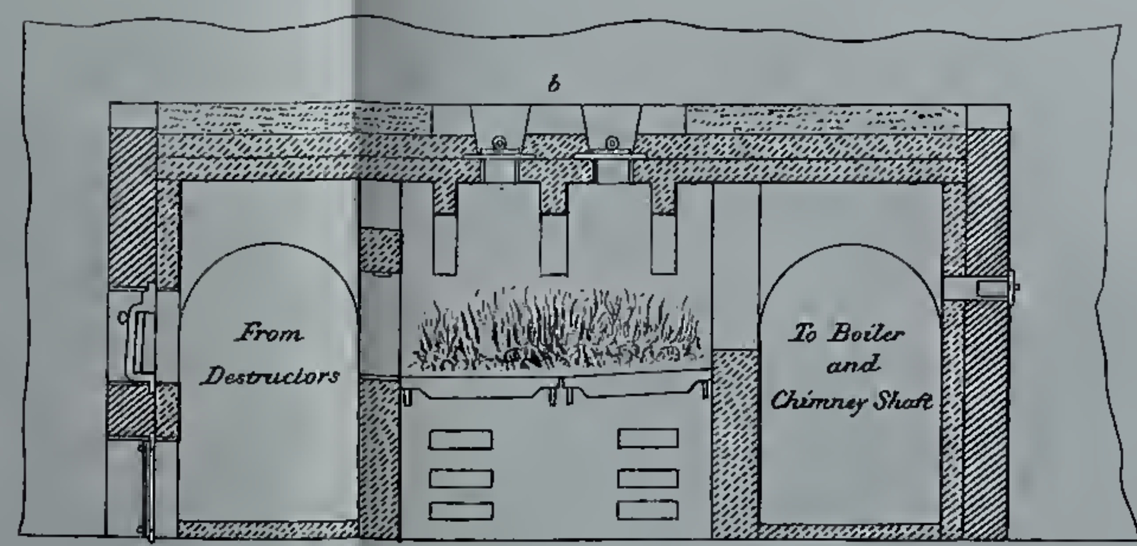
a. Dust Chamber & Main Flue. *c.* Air regulating Flues.
b. Feed holes. *d.* Iron door.



Plan.



Section B.B.



Section C.C.

Scale, 4 Feet to an Inch.

J Akerman Photolith London

The foregoing represents the house refuse and sludge, which, taken together, give

£7 6*s.* 9*d.* × 52 weeks = £381 11*s.*, say £380.

The above statement as to labour includes more than should really be charged to the destructor, as the men are engaged part of the time in the yard, pumping out and other general work. Half the foreman's time is also charged to destructor.

For about six weeks in the year the fires are banked up, and there is little labour on the destructor ; but no credit is taken for this, nor is there for the hard core from dust, such as tins, etc., although the labour of picking over is charged in "expenses."

The furnaces are seldom banked up on Sunday, but when this is done the furnaces are filled with refuse and the dampers nearly closed.

Cost of destructor, etc. :—

	£	*s.*	*d.*	£	*s.*	*d.*
Chimney-shaft	730	0	0			
Cost of 4 cells, fume cremator, and boiler	1,270	0	0			
				2,000	0	0
Repayment of principal and interest per annum on £100, 30 years at 4 per cent.				5	15	8
Repayment of principal and interest on £2,000				115	13	4

Two of our cells and the cremator were built out of current account, and not out of loan, so there are no annual repayments in respect of these, but the author has included the cost in above amount. For the destructor itself no machinery is necessary, but, of course, if it is desired to utilize the heat given off to raise steam, a boiler is required. Other machinery, of course, depends upon the requirements of the works. At Ealing there is a six horse-power engine, which drives the liming machine, clay mixer, works' lift, chain pump, special pump, etc., sludge ram, mortar-mill, etc., and there is steam sufficient to work all the above and additional machinery if required.

A considerable saving is being effected by using the hard clinker as a base for tar paving, thereby causing a saving of 30 per cent. ; also on a concrete paving, which can be laid for 3*s.* per yard sup., York paving costing 6*s.* 4*d.* per yard sup. The finer material from ashpit, which contains a good deal of recalcined lime, makes a splendid mortar mixed with one part of lime to five of ash, and the clinker when ground makes a good mortar with usual proportions. In the above account no special credit has been taken for these items. At the present time (1898) there are seven cells at Ealing, with a corresponding increase of machinery, but the mode of working is identically the same as in 1887 ; the population has increased to 33,000, but the general expense of working is somewhat less, in proportion to the increase.

Battersea.*—"This is another district adjacent to London, and has a population of 150,000. At this town they also burn the house refuse, and have erected one of Manlove, Alliott & Co.'s patent destructors, with twelve cells constructed back to back, provided with Jones's patent fume cremators, and with a chimney stack 150 feet in height (Plates LVII. and LVIII., facing this page). The works were completed in February, 1888, at a cost of about £11,400, including the chimney-shaft, mortar-mill house, engine house, two incline roadways, and a multi-tubular steel boiler, twelve feet long by eight feet in diameter, attached to one of the flues, and which is to be heated with the waste heat from the destructor, and it is estimated that this will create a steam-power of 60 lbs. pressure to the square inch, sufficient to drive an engine of from 50 to 60 horse-power, for working the mortar-mills, etc., attached to the works, and without any additional cost. The boiler is suspended from heavy cast-iron girders, supported upon walls surrounding the boiler and flues. Each cell consumes about 7½ tons per day of twenty-four hours, or 28,000 tons per annum for the twelve cells, the fires being banked up on Sundays. This destructor is situated in a populous district, but operations are conducted so successfully that there is no complaint of any nuisance arising from burning the refuse. The residuum is here dealt with in several ways. New stables, workshops, and manager's house have been built at the depôt, and the yard being paved from the manufactured clinker, the whole of the buildings present a very pleasing and durable appearance. Artificial stone slabs for footpath paving are also very extensively made here, as well as a large quantity of materials prepared for laying tar paving, many footpaths having been satisfactorily laid with both kinds. An inspection was made of specimens of the paving laid, which had a nice cleanly appearance, and compared very favourably with other methods. The surveyor also stated that they were prepared to undertake private paving at 2*s.* per yard, which, after all expenses had been paid, would leave them a good margin of profit. Mortar is also made from the clinker, but up to the present the whole of it has been required for their own purposes. The house refuse is here satisfactorily dealt with at a cost of 1*s.* per ton per annum."

Liverpool.—Messrs. Manlove, Alliott & Fryer's slow combustion type of destructor is employed at Liverpool. It has twenty-four cells and is provided with a Jones' cremator at the foot of the chimney, which is 170 feet high; the cells have a temperature of 700° Fahrenheit. Old tins are picked out before burning and sold at from 1*s.* 6*d.* to 2*s.* 6*d.* per ton, the purchaser removing them from the premises. The ash and

* *Report on the Destruction of Towns Refuse, and Disposal of the Residuum, to Aston Manor Local Board*, 1889, by W. A. Davies, H.A.I.C.S., Engineer and Surveyor to the Board.

PLATE LVI.

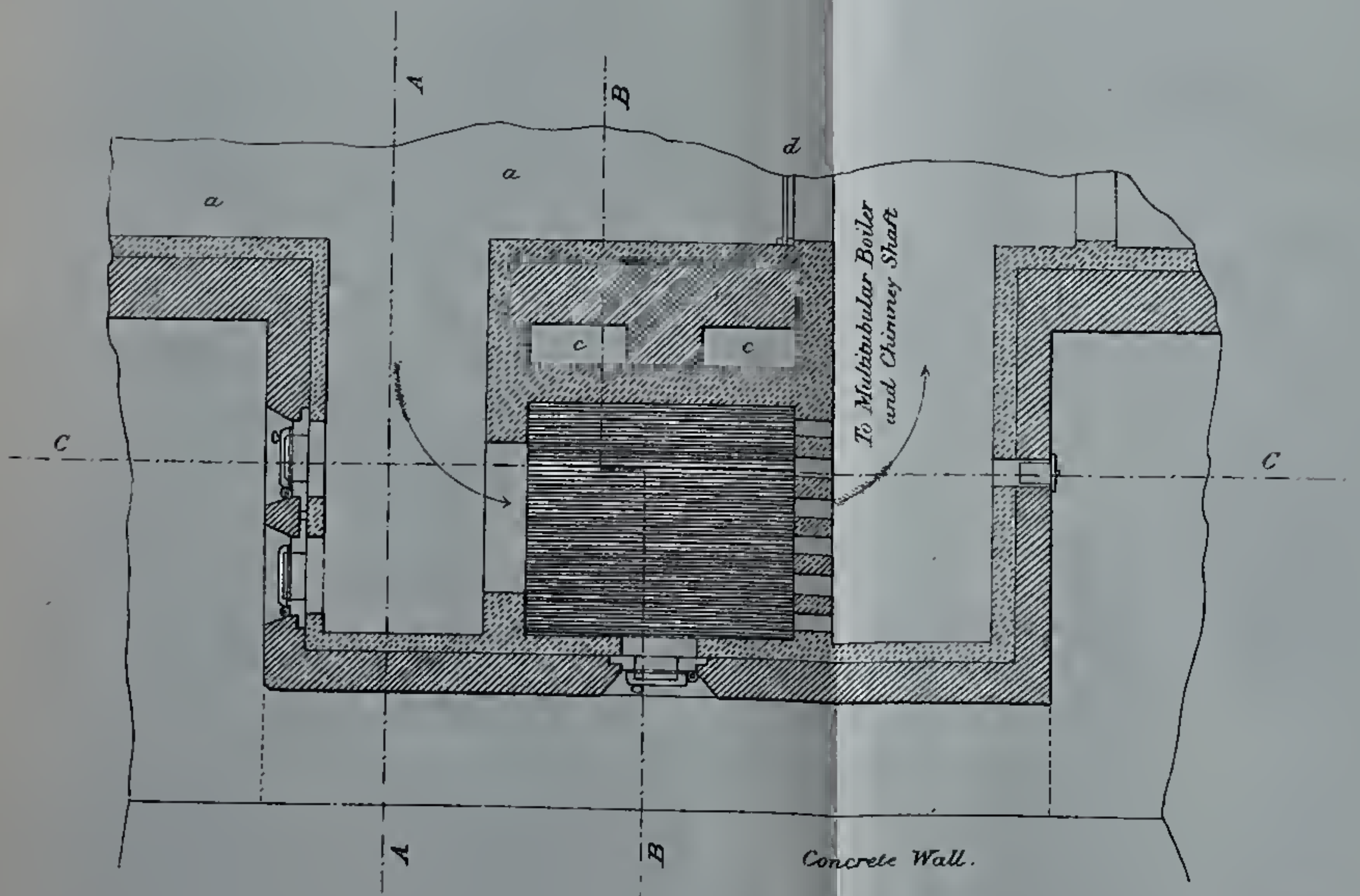
JONES'S PATENT "FUME CREMATOR".

AS IN USE AT

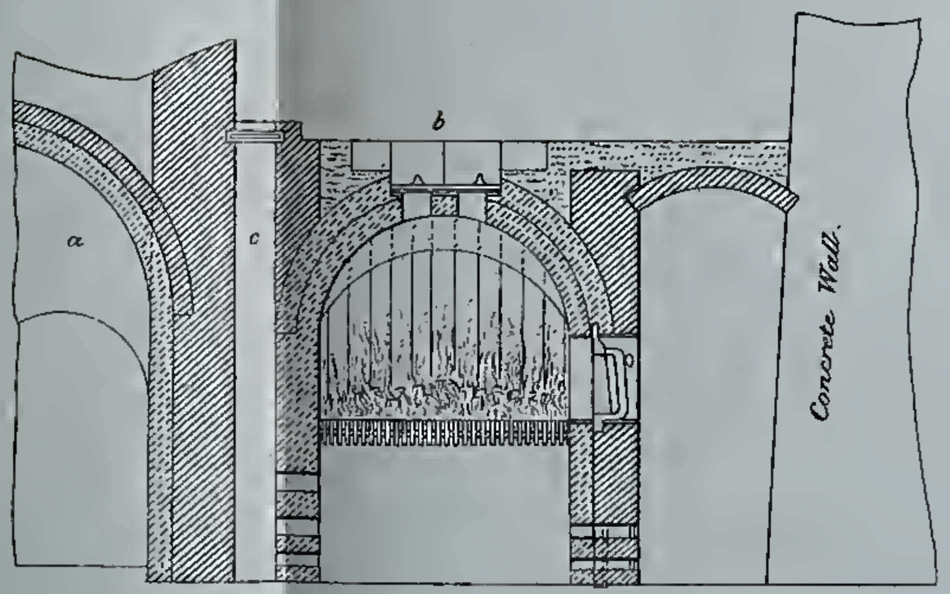
EALING, MIDDLESEX.

REFERENCE.

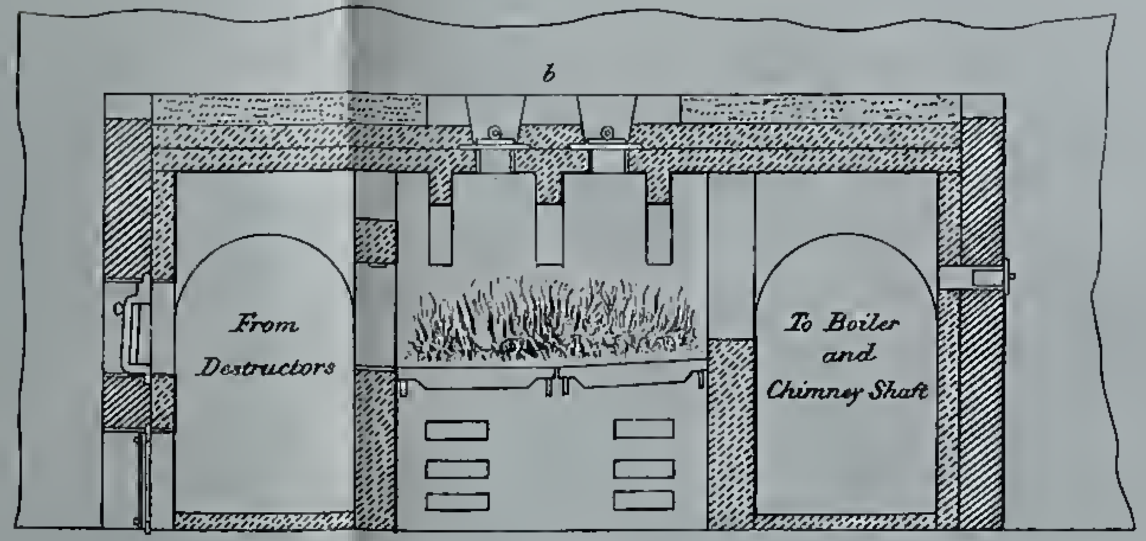
a. Dust Chamber & Main Flue. *c. Air regulating Flues.*
b. Feed holes. *d. Iron door.*



Plan.



Section B.B.



Section C.C.

Scale, 4 Feet to an Inch.

J Akerman Photolith London

greater part of the clinkers are discharged at sea by means of steam hoppers. The best of the clinkers are set aside for the manufacture of compressed cement concrete slabs. Messrs. Boulnois & Brodie's patent charging tanks are used for charging twelve of the cells, and effect a great saving in labour. They also supply ample storage for the refuse, so that two men can fill the twelve cells provided with these tanks, instead of five men to do similar work for the other twelve cells.

The waggon runs on rails, is divided into compartments, eight or so in number, and the carts conveying the refuse are tilted right into the waggon compartments. Each compartment contains a full charge for a destructor cell, and the waggon being run over the feed-hole of the cell, the cover of the cell and the bottom of the compartment of the waggon can be simultaneously opened, when the charge of refuse at once drops into the cell and immediately thereafter the cell and compartment are again closed up. The whole operation is a question of seconds, and there is practically no dust evolved and no smell disengaged.—*The Journal of the Society of Chemical Industry*, March 31st, 1896.

The cost is thus reduced to $7\frac{1}{4}d.$ per ton, effecting a saving of $3d.$ per ton on the labour involved on all the refuse consumed in these cells. The refuse from the destructors is discharged from 22 to 26 miles out at sea, at a cost of *2s.* per ton; but Mr. Boulnois, C.E., has succeeded in utilizing the best of it for making paving; the necessary plant was manufactured for him by Messrs. Musker, of Liverpool. The clinker concrete flagging is made with Portland cement, and is $2\frac{1}{2}$ inches thick; it is subjected to a pressure of $2\frac{1}{4}$ tons per square inch, which expels all the surplus water. The cost per yard super. is $1s.\ 7\frac{3}{4}d.$

The Horsfall Patent Refuse Furnace.—The Horsfall destructor (Fig. 520) consists of a number of cells or furnaces arranged in a row side by side. Each cell is eleven feet deep by nine feet broad and eleven feet high. As in the case of Fryer's destructor, the refuse is carted up an inclined road at the back, and tipped on to a floor at a convenient level for feeding into the furnaces. The furnace is divided into two parts—first, the hearth on which the refuse is dried before being raked on to the fire-grate. The fire-bars are so made that a rocking movement can be imparted to them, so as to break up the clinker which is raked out at the lower end. The feeding, cleaning, and clinkering are effected by doors provided for the purpose, and which are only opened in order to conduct either of these operations.

A forced draught is arranged for each furnace by means of a pair of steam-jets under the hearth; the draught circulates first under the hearth, then through the sides of the furnace and into the ash-pit by a series of holes, from whence it has access to the furnace through the grate bars. The air is thus heated before it reaches the fire, and a temperature of 2,000° Fahrenheit is attained in the furnace. This high temperature is due to the forced draught and the formation of water-gas by the decomposition of the steam as it passes through the body of the fire. This gas again burns in combination with the gases given off from the fuel on the hearth and in the fire, forming large flames in the flues at some distance from the grate, thus entirely destroying all noxious fumes and germs. The furnace is so arranged that none of the gases given off by the "green" refuse in drying can escape this

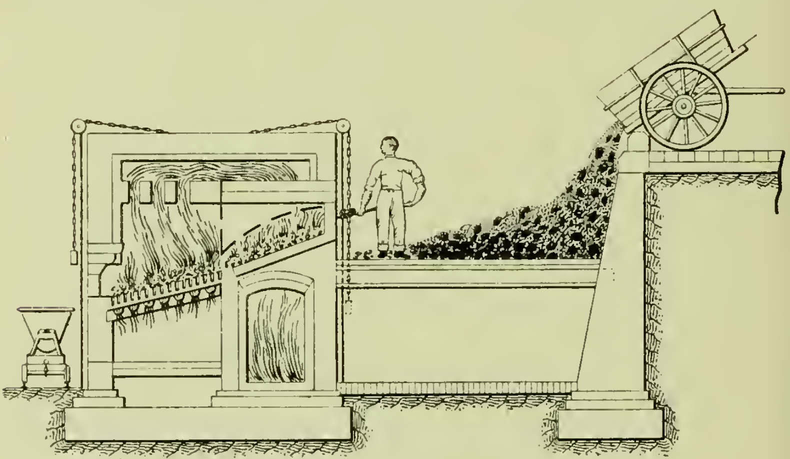


Fig. 520.—The Horsfall Refuse Furnace.

action, as the only openings from the chamber are in the front and immediately over the hottest part of the fire.

The pressure in the ashpit is equal to that of half an inch of water, A mattress chamber is formed by enlarging the flue beyond the furnace, so that bulky articles may be readily cremated. A special means of access is provided.

In addition to the high temperature attainable in this furnace, there is the additional advantage that there is no inrush of cold air when any of the doors are opened for feeding, clinkering, etc., and only a slight suction is required in the chimney, consequently the draught up the latter is purposely checked ; the effect of this is that dust and unburnt paper are not drawn away from the fire and up through the chimney, to the annoyance of the neighbourhood.

The heat thus obtained can be transformed into useful power, and steam generated for electric lighting and other purposes.

A furnace of the ordinary type has a fire-grate area of from twenty-five to thirty square feet, and is capable of burning about seven tons of ordinary house refuse in twenty-four hours. It has been calculated that the latent energy thus capable of being utilized amounts to 20 indicated horse-power per hour ; the cost of working is 5*s*. per cell per day. A destructor of the Horsfall type has been constructed at Oldham, and thirty cells are about to be erected of the same type at Hamburg.

Warner's Patent "Perfectus" Destructor.—This destructor with the latest improvements is represented in Plate LIX. A high temperature is maintained and special arrangements are provided to prevent fine dust passing out of the cells into the flues, and should any portion be carried forward, it is caught in dust pits connected with the main flue. Mechanical appliances are provided for the regulation of the draught. It is claimed that the clinker and fine ash come out in the proportion of about 25 per cent. of the refuse consumed. The whole process is carried out without causing any smell, the gases being completely consumed in the cremator and other apparatus.

This destructor has been adopted at Hornsey, Bournemouth, Winchester, St. Luke's, Royton, Hyde, Govan, Kensington, Newcastle-on-Tyne, St. George's, Glasgow, and other places. It is made by Messrs. Goddard, Massey, and Warner, Nottingham.

The "Bennett-Phythian" Constant High-Pressure Destructor.—This destructor has been designed by the inventors to attain a constant temperature of 2,000 degrees, so as to efficiently destroy refuse and all noxious gases given off in the process. Figs. 521 and 522 represent sections of a destructor, designed for a moderate-sized town, which is stated to be capable of destroying twenty-four tons of refuse in twenty-four hours.

Messrs. Ham, Baker & Co., the makers, claim that it is more effective than any other, and will utilize the heat generated to the fullest extent, that the temperature is maintained during the processes of clinkering and recharging, so as to be practically constant. By this means also the deterioration of the interior of the cell is avoided, as it has been found in other destructors to be accelerated by the variations from a high temperature downward.

The following is the method of working :—One cell is empty whilst the fires are burning in the other two, and a maximum heat is obtained in the central cell. When it becomes necessary to recharge it, the grate is moved so as to bring that portion which was in the centre into the empty side cell, and that portion which was in the outer into the centre cell, and thus the central cell is recharged by introducing refuse from another cell which has been gradually increasing in heat. The grate that has been shifted into the empty cell is then clinkered and recharged, and the blast turned on to it, when it gradually increases in temperature, the products of combustion from it passing over the hotter fire in the centre, until that in its turn requires recharging ; and thus the side cells

Fig. 521.

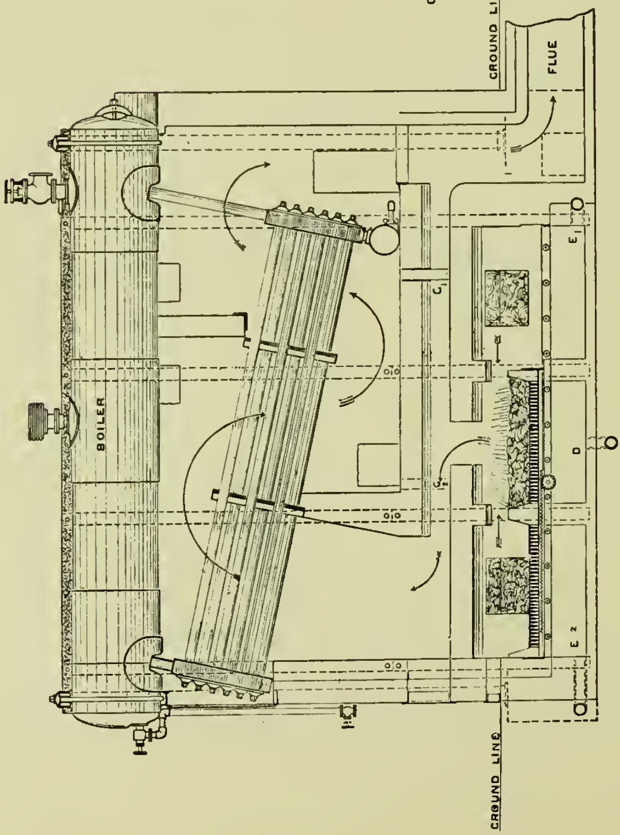
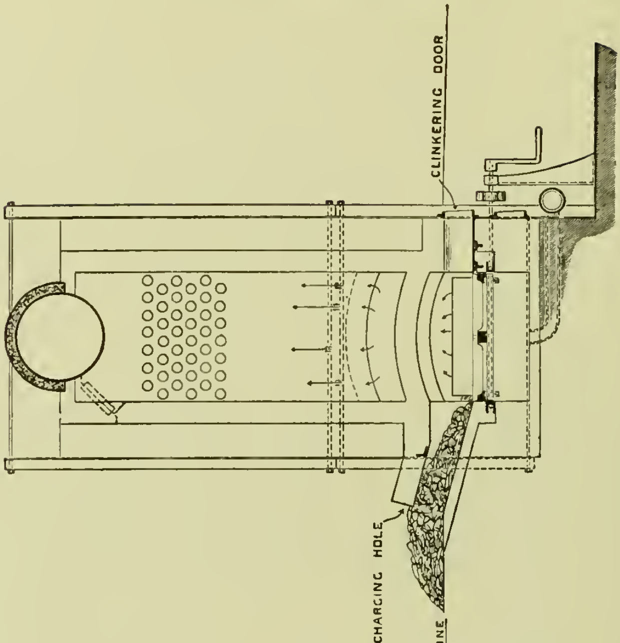
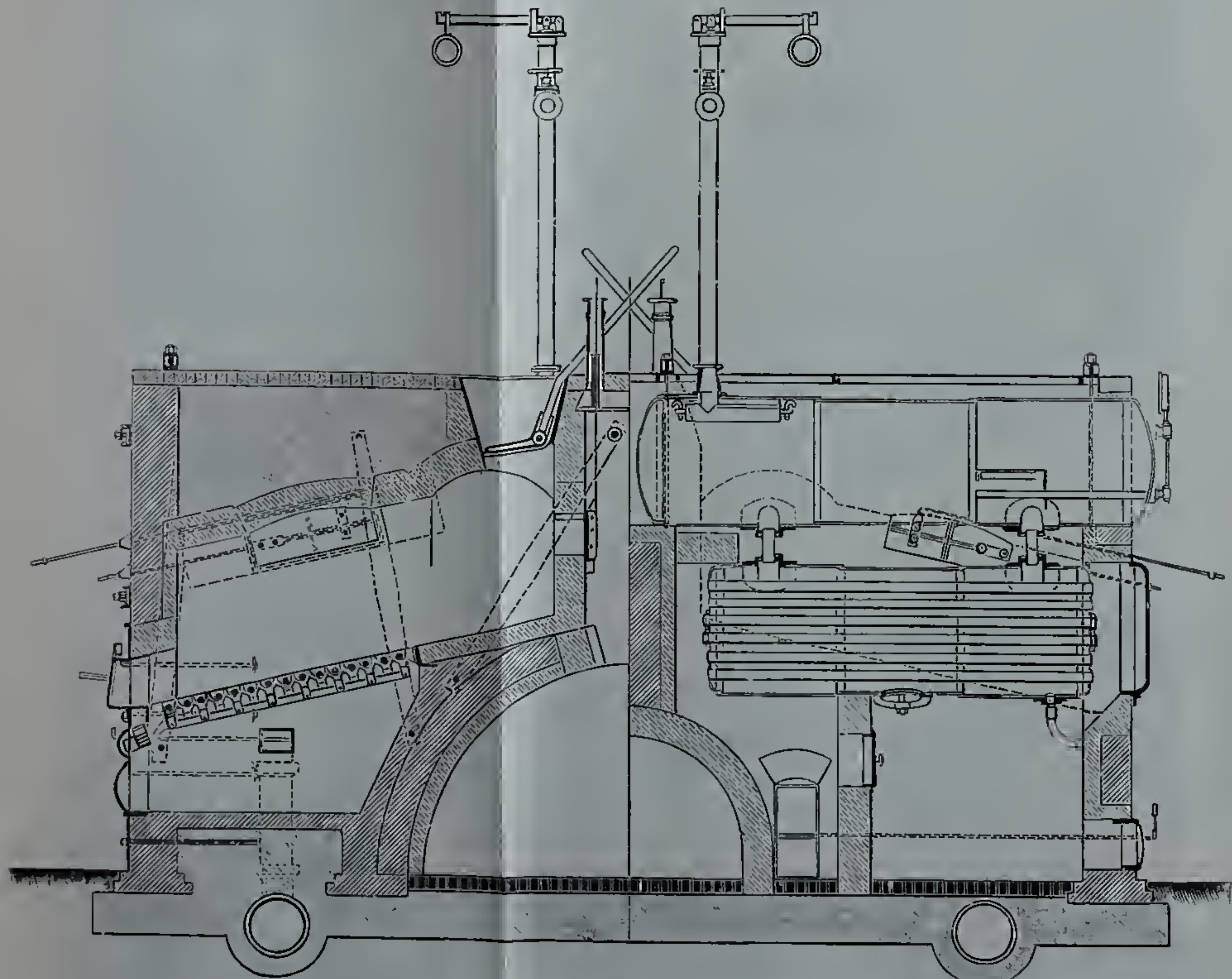


Fig. 522.



The Bennett-Phythian Constant High-Pressure Destructor.

WARNER'S PATENT "PERFECTUS DESTROYER."



Scale: ¼ inch to a foot.

To face page 556.

are alternately recharged and the grate shifted with its charge into the central cell. The grates are shifted by means of a rack and pinion, but it is contemplated to utilize an electric motor for the purpose. The gases after leaving the central cell can be utilized for raising steam and maintaining it at a constant pressure by means of a water-tube boiler. It is considered more economical to mount the boiler above the destructor, though it may be placed at the end or side. The charging is from the ground level.

The Beaman and Deas Patent Destructor.—This destructor is shown in Plate LX., facing page 556.

The plant consists of eight destructor cells built in pairs back to back. Each pair of cells has a common combustion chamber, from which the products of combustion pass into the main flues leading to two 96 H.P. Babcock and Wilcox water-tube boilers, and thence by underground flues to a chimney 150 feet in height.

The refuse to be consumed is charged through hoppers (which have no doors, but are usually covered with the refuse) on to an inclined hearth leading to a horizontal grate, the bars of which are set very close together. The ashpit is closed and a forced draught, at a pressure of about two inches, is supplied by a fan. On the side of the grate opposite that from which the refuse is fed in is a firebrick chamber wall, and beyond this is a narrow vertical firebrick chamber (called the combustion chamber), where the burning gases meet a secondary air supply, designed to aid the consumption of any unoxidised products which they may contain.

The refuse about to be burned, lying on an inclined hearth, is partially dried by the radiant heat from the refuse which is already burning on the grate, and when it is drawn down on to the grate does not smother the fire, but begins to burn readily.

This destructor has been adopted by the Leyton Urban District Council during the last three years for the destruction of sludge and refuse in the proportion of one to two respectively. The following are the quantities of sludge and house refuse dealt with in four cells at the destructor works during the year 1897 :—

Refuse...	10,952	tons.
Sewage sludge	5,795	,,
Total ...	16,747	

As each week consists of only $5\frac{1}{2}$ working days, these figures show an average daily consumption of $14\frac{1}{2}$ tons. The refuse consists of a mixture of ordinary house refuse and filter-press cakes of sewage sludge from the Leyton Sewage Works. The sludge contains about 64·86 per cent. of water. The average pressure of air in the ashpit is two inches of water. The quantity of water evaporated is 0·426 lbs. per lb. of fuel, and according to the report of Sir Douglas and Mr. Francis Fox, the total weight of water evaporated on the occasion of their inspection was 31,920 lbs., and assuming an average consumption of 20 lbs. of water per indicated horse-power, the horse-power available would be 133 I.H.P. The equivalent amount of steam coal which would be required to obtain this result is 1¾ tons. The temperature of the combustion chamber when the charge was burning freely was found to be 1,562 degrees Fahrenheit. The following Table gives the results of the trial of the steam-raising value of the refuse and sewage cake :—

" Duration of trial, 10 a.m. to 10 p.m., March 30th, 1897...	12 hours.
Number of cells of destructor in use...	4 ,,

DETAILED RESULTS OF TRIAL.

	Tons.	Cwts.	Qrs.		Lbs.
Weight of house refuse consumed...	22	5	0	=	49,840
Weight of sewage cake consumed...	11	4	1	=	25,116
Total weight of material burnt	33	9	1	=	74,956
Proportion of house refuse to sewage cake	100 : 50·4			=	2 : 1 (nearly)
Average weight of material burnt per cell per hour ...					1,561
Total weight of clinker produced...	9	16	2	=	22,008
Proportion of clinker produced to material burnt ...					29·4%
Average steam pressure in boilers					105 lbs.
Average temperature of feed water					65° F.
Weight of water evaporated	3,192 gals.			=	31,920 lbs.
Weight of water evaporated per hour					2,660 ,,
Weight of water evaporated per lb. of material burnt					0·426 ,,
Corresponding with					
Weight of water evaporated per lb. of material burnt from and at 212° F.					0·507 ,,
Average pressure of air in ashpit					2 inches of water."

The following are conclusions arrived at by Sir Douglas Fox and Mr. Francis Fox as the results of their trial :—

" From the consideration of the results of this trial we have arrived at the following conclusions :—

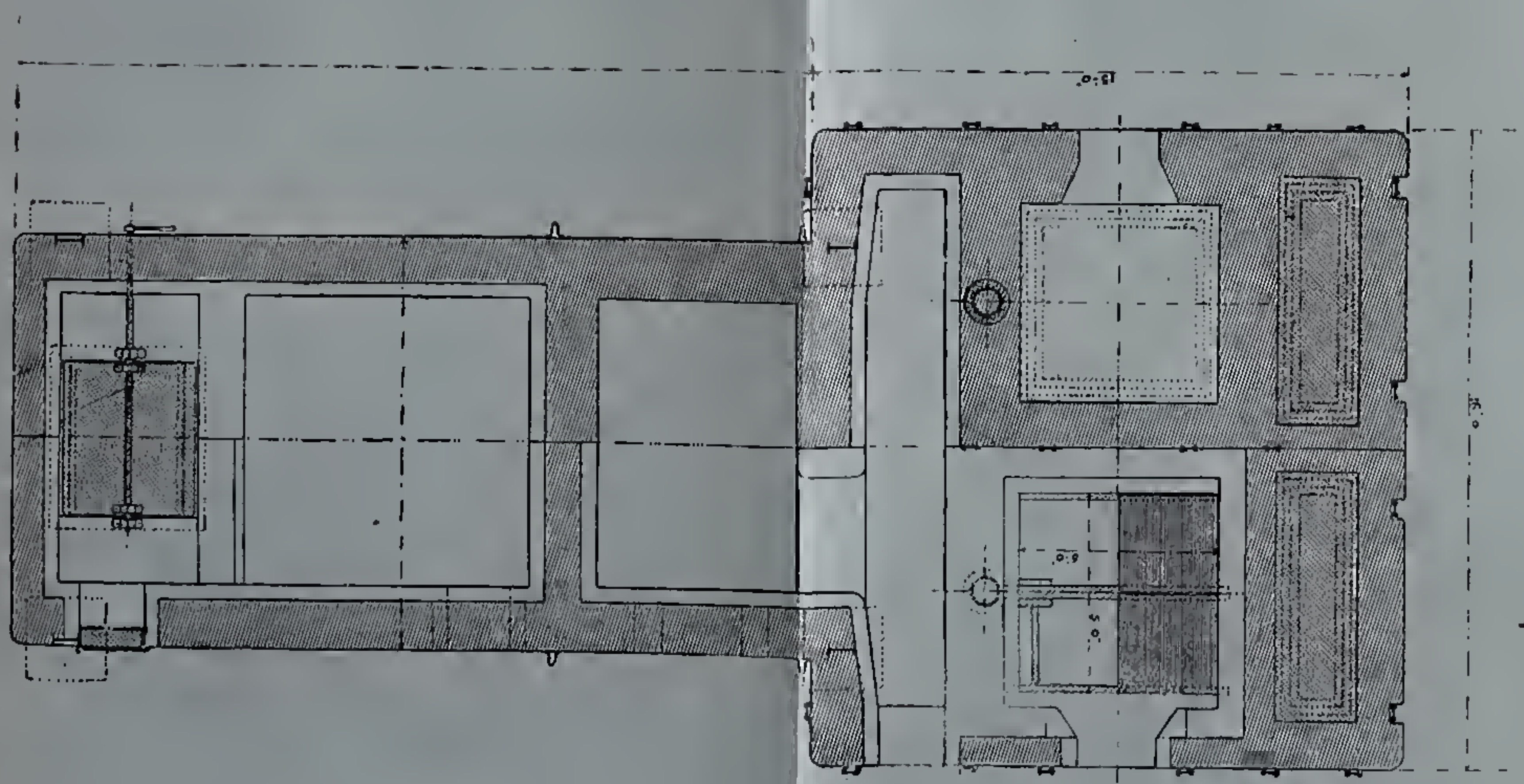
" 1. The destructor is capable of consuming wet sewage cake and house refuse of poor character in a complete and satisfactory manner.

" 2. The oxidation of the combustible matter in the material fed into the destructor is complete, and the gaseous products of combustion are inoffensive.

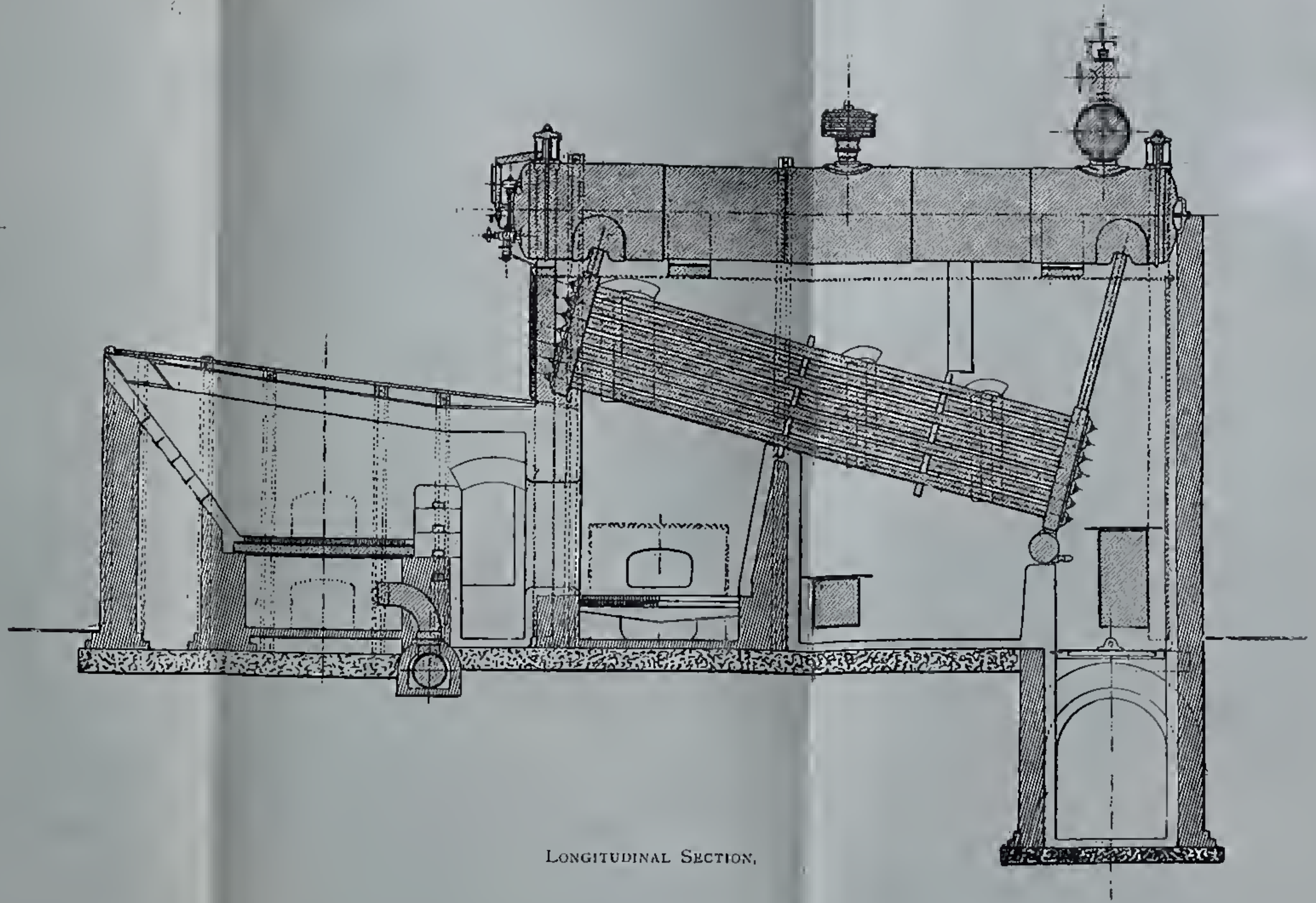
" 3. The gaseous products of combustion are sensibly free from any suspended matter by the time they pass into the flue to the chimney.

" 4. The clinker is well burnt and free from offensive half-charred carbonaceous matter.

THE BEAMAN & DEAS PATENT DESTRUCTOR, WITH BABCOCK & WILCOX BOILER.



Plan.



Longitudinal Section.

To face page 560.

"5. Even when working with a wet sewage cake and poor house refuse, the destructor generates more heat than can be used with the present plant at Leyton.

"We therefore consider that your destructor provides an efficient and economical method of destroying the refuse of towns without injury to the neighbourhood. So far as we are aware, it is the only form of furnace yet adopted capable of burning a considerable proportion of sewage sludge—even when containing as in this case a high percentage of moisture."

The Beaman and Deas Destructor has been adopted at Dewsbury, Wandsworth, Tiverton, and other places.

The Meldrum Refuse Destructor.—The ability to use ordinary town refuse and garbage for fuel in generating steam power has been demonstrated by steam engineers, but as yet but little attempt has been made in this country to apply the principle. On the other hand, this fuel has been used to a considerable extent abroad, showing the system is quite feasible and practicable. The chief advantage, of course, lies in the fact that this material can be usually secured from the city authorities for nothing, or, in some cases, a price might be secured for carting away and disposing of it.

Many opinions have been expressed as to whether the amount of power obtained warrants the increased outlay such a plant would entail. Some have advocated, as the most economical method, burning the refuse at the temperature required to render all fumes harmless, as the wear and tear on the furnace is then very small and the cost of repairs a minimum. Until the past two or three years practically all the furnaces erected in England have been constructed on this principle. They have in all cases had a high chimney to carry away any fumes that escaped cremation; but so numerous were the complaints made by those living in proximity to the works, that it was found necessary to furnish some means to abolish this nuisance. To meet this difficulty the fume cremator was invented. This consists of a reverberatory arch, with baffle brick ribs projecting from it, serving to deflect the gases on to the top of a red-hot coke or coke breeze fire. This adds to the cost of destruction about $3\frac{1}{4}d.$ per ton of refuse.

To effectually destroy refuse it is necessary that complete combustion take place in the furnace, and no gases or vapours distilled from the freshly charged material should leave the furnace without being rendered totally innocuous; the heat in the escaping gases can then be used for generating power. Messrs. Meldrum Brothers, having had an experience in burning low-class fuels with their patent system of forced draught, and noting that the results obtained in the ordinary destructor cells were in the majority of cases unsatisfactory, were eventually led to make some preliminary tests. Their first attempts were made in the ordinary types of Lancashire and Cornish boilers; that the results were satisfactory the following test, made at Salford Sewage Works, will show.

Boiler, Lancashire, 28 ft. long, 7 ft. diameter, 2 ft. 9-in. flues. Fuel used, unscreened refuse. Duration of test, 14 hours 10 min. :—

Weight of unscreened refuse burned, lbs.	18,704
Average steam pressure, lbs.	50·5
Temperature of feed water, degs. Fahr.	42·9
Water evaporated during test, lbs.	36,000
Refuse burnt per hour, lbs.	1,320
Water evaporated per hour, lbs.	2,540
Water evaporated in lbs. per lb. of refuse from feed	1·9
Water evaporated per lb. of refuse from and at 212° Fahr. ...	2·28

It follows that to destroy a considerable quantity in this manner would require an extensive outlay in plant; neither could it be expected that the high temperature necessary for the total destruction of the fumes could be obtained in the ordinary boiler furnaces, owing principally to the large quantity of clinker, small grate area, and limited space above grate level. Having satisfied themselves that power could be obtained from ordinary unscreened town's refuse, and that such results had not been previously equalled, they designed a furnace which should destroy a large quantity of refuse and conform with all the requirements of an efficient destructor. Naturally, there were many preliminary difficulties and prejudices to contend with. The old type had a great hold, and many were too incredulous to believe such results as those given could possibly be obtained.

The first destructor to generate steam as well as consume the refuse was erected at Rochdale. It consisted of two cells, each having a grate area of 45 square feet, which was again divided into two separate or smaller grates by means of brick division walls built in the ashpits and carrying cast-iron division T's—with their thin edges level with the top of the firebars. This enables one half of the grate to be cleaned while the other half is in full work, consequently the temperature of the furnace is reduced very little, and all noxious fumes mingling with the gases from the incandescent fire are entirely destroyed. At the back of these grates, behind the bridge, is a combustion chamber common to the two cells, serving as a setting pit for the fine dust, and in which the gases are further mixed. From this chamber the gases are led to the boilers. The latter are of the Lancashire type, one to each cell, 8 ft. diameter, 30 ft. long, flues 3 ft. diameter, set in the ordinary method. The following test, taken in the presence of a well-known engineer, will vouch for the efficiency of the plant.

Evaporative test of unscreened ashpit refuse burned in Meldrum furnaces fitted in front of two Lancashire boilers 30 ft. by 8 ft., with two flues 3 ft. in diameter, at the Rochdale Sanitary Works, March 1, 1895 :—

Duration of test, hours	6
Average steam pressure, lbs.	113
Average temperature of feed water, degs. Fahr.	53
Total water evaporated, gals.	4,207
Total refuse burned, tons...	11·4
Total residue (clinker), tons	4·15
Temperature in combustion chamber at 4 o'clock, tested with Siemens' pyrometer, degs. Fahr.	1,988
Temperature at 4.30 after clinkering and feeding	1,290
Water evaporated per boiler per hour, gals.	350
Refuse burnt per hour, lbs.	1,280
Water evaporated per lb. of refuse (actual), lbs.	1·64
Water evaporated from and at 212° Fahr.	1·97
Percentage of clinker to refuse, per cent.	36
Moisture not known.	

Blowers supplied with steam at 55 lbs. pressure from separate range of boilers.

Two destructor furnaces on similar lines were erected in front of two Galloway boilers at the Sewage Outfall Works, Hereford. Here each cell was separated entirely, although provision was made to have the combustion chamber common to both furnaces if required. The Galloway boilers are each 22 ft. long, 7 ft. diameter, 2 ft. 9 in. flues, and the steam generated is used for pumping 1,250,000 gals. of sewage effluent per day of ten hours, sludge presses, lime mixing, and other auxiliary plants. Tests made by Mr. Jno. Parker, the city engineer, have satisfied him that the evaporation obtained is quite $1\frac{1}{2}$ lb. of water per lb. of refuse, and, since the furnaces commenced working, no coal or coke whatever has been required. That the temperature is high may be judged when it is stated that the copper balls of a Siemens water pyrometer were melted in the combustion chamber, indicating that there was a temperature of at least 2,000° Fahr. Here and also at Rochdale there is a stalactitic formation on the brickwork which serves to protect the structure. Analyses of the gases taken gave an average of 16 per cent. by volume, though readings up to 20 per cent. CO_2 were taken. These were given by Arndt's reconometer and checked at the same time by the Orset apparatus. There was also an entire absence of CO. Forced draught on the well-known system of Meldrum was used in all the previously mentioned tests, and the results seem to prove that a perfect system of forced draught is absolutely necessary. So successful have the Rochdale and Hereford destructor plants proved that Meldrum Brothers have received orders to erect plants of larger capacity from two municipal authorities, both orders being the result of deputations to see the destructors mentioned. Both these new plants will be of the

THE "MELDRUM" REFUSE DESTRUCTOR.

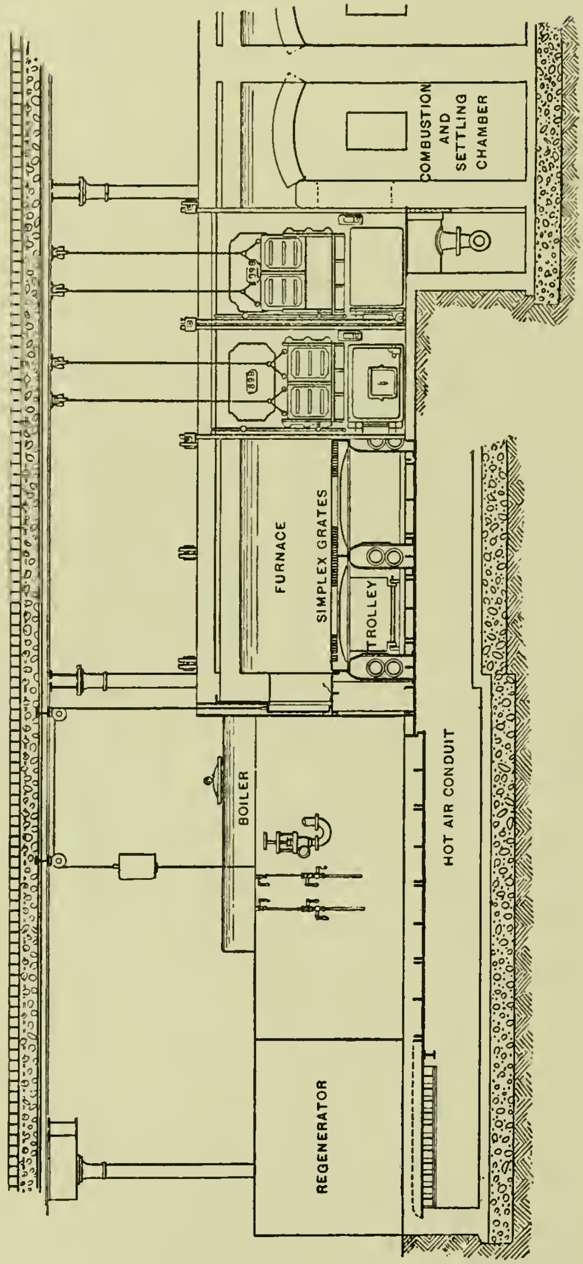


FIG. 523.—Front Elevation of Boiler with Refuse Destroyer.

construction shown in Figs. 523—527, and in each case they have to provide steam, one in conjunction with the electric light station, and the other in pumping sewage effluent. They will have Meldrum's patent simplex system of grate, the construction of which will be readily followed on reference to Figs. 523, 524, 525. The plant consists of simplex grate, Lancashire boilers, settling combustion chamber, continuous tubular regenerator, this combination being termed a unit. The simplex grate is divided into four separate working grates by means of cast-iron division boxes in the ashpit, on the top of which are carried the cast-iron T pieces ⊥ with their thin edges level with the top of grate bars. Each portion of grate so divided has separate firing doors ; there will also be noticed at the end grate a large door, through which mattresses, diseased carcasses, etc., will be charged. There is also a portion of the grate for about 2 feet in width of the front bars made to tip, so that all clinkers may be raked through the opening thus formed into the ashpit or a trolley introduced there. The spaces between the bars will be narrow, about $\frac{1}{8}$-in., as is the custom in this system of forced draught. The furnace and ashpit fronts will be substantially constructed, the ashpit being entirely closed, so that all the air for combustion will be supplied by means of the steam jet blowers of the Meldrum type, projecting inside the cast-iron division boxes, which are carried by air boxes, connected with the hot-air conduit from regenerator. The ashpit front has a large hinged door, so that an ash car may be introduced to receive the hot clinkers which, while cooling, give up their heat to the air and can afterwards be wheeled away without inconvenience to the fireman. As an alternative to the tipping grate, the dead plate may be made to tip and the clinker dropped on the ashpit to cool. With the grate described it follows that an evenly high temperature may always be maintained by careful and systematic firing, one grate being cleaned while the others are in an incandescent and semi-incandescent state. Thus all noxious fumes must be destroyed, and no paper or other light material can pass unburned to the chimney. The gases of combustion will pass over the bridge into the combustion chamber, where the major portion of the dust will settle through openings in the combustion chamber along the flue tubes of the Lancashire boiler, which is set in the ordinary method. After leaving the boiler the gases pass through the regenerator tubes to the chimney flue. This continuous regenerator (Figs. 526, 527) is a new departure in the destruction of refuse. It has proven successful in many cases, and will, no doubt, be of inestimable benefit when the fuel is damp or of low calorific value and varying quality, as refuse, insuring an increased rate of combustion. It will be constructed of a number of cast-iron tubes suitably carried on cast-iron plates, allowance being made for their free expansion. The

THE "MELDRUM" REFUSE DESTRUCTOR.

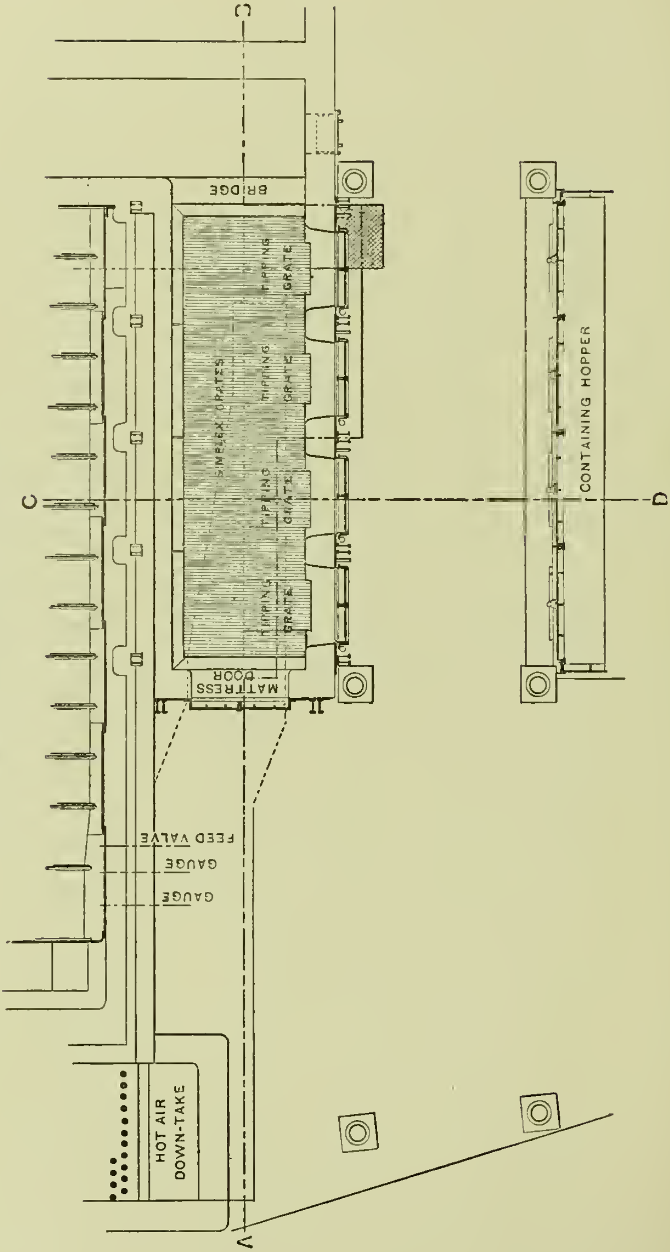


FIG. 524.—Plan of Grate with Boiler Settings.

gases from the boiler pass down the tubes to the chimney flue. The air to be heated will be drawn from the tipping floor overhead, circulated around the tubes, and be led away to the hot-air conduit, which runs under the ashpit floor of furnace, suitable openings being left for the air to pass to the air boxes, carrying blowers. The engravings show an overhead platform and portion of another unit. As the platform will be of an ordinary construction, it is unnecessary to describe it. The method of firing will be by hand, the refuse being tipped from the cart into the containing hopper (Figs. 524, 525), which will have a capacity equal to a day's supply.

In charging destructors many favour the hopper method of feeding on to a drying hearth; but if it is carefully considered it will be seen

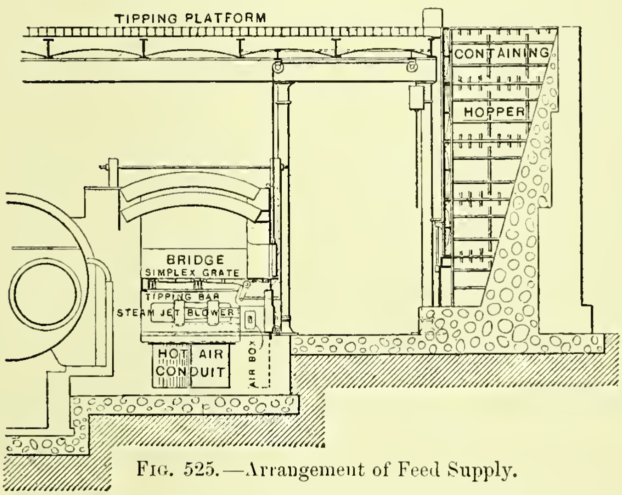


Fig. 525.—Arrangement of Feed Supply.

that hand firing is to be preferred at the same time, and gives the better result, necessitating only two handlings of the refuse as against three by hopper charging, viz., charging and clinkering in the former case, and charging, shaking down, and clinkering in the latter.

It will perhaps be interesting to see what power can be obtained from a plant of this type. The boiler adopted is of the Lancashire type (Figs. 526, 527), 8 ft. diameter, 30 ft. long, and flues 3 ft. 2 ins. in diameter constructed for a working pressure of 200 lbs., which is to be reduced down to 150 lbs. The heating surface of such a boiler may be taken at 1,050 square feet; this, at a rate of evaporation of 6 lbs. of water per square foot of heating surface will evaporate 6,300 lbs. of water per hour from feed at 160° Fahr., or assuming 20 lbs. of steam per i.h.p. will be equal to 315 i.h.p. Now the grate area will be 95 square feet, and the rate of combustion may be taken at about 42 lbs. per square

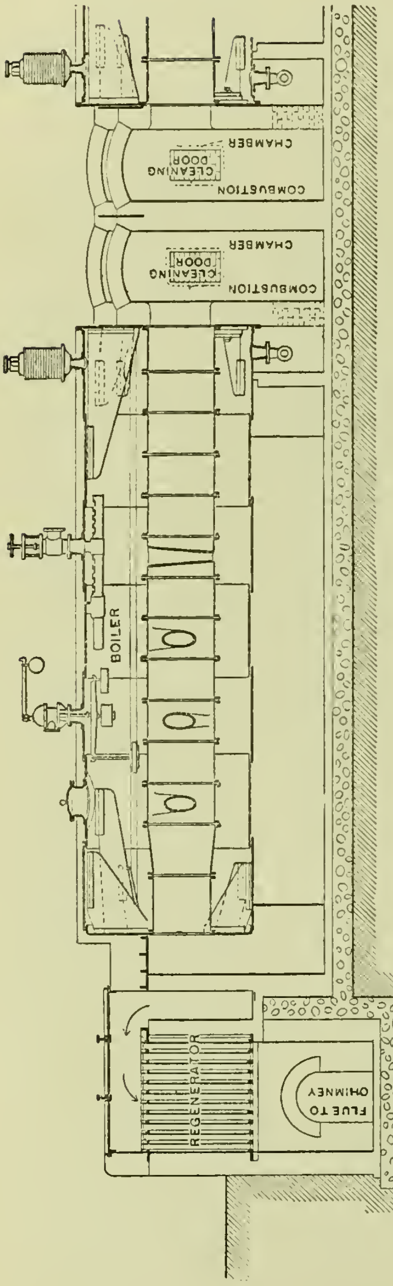


FIG. 526.—Longitudinal Section of Continuous Regenerator.

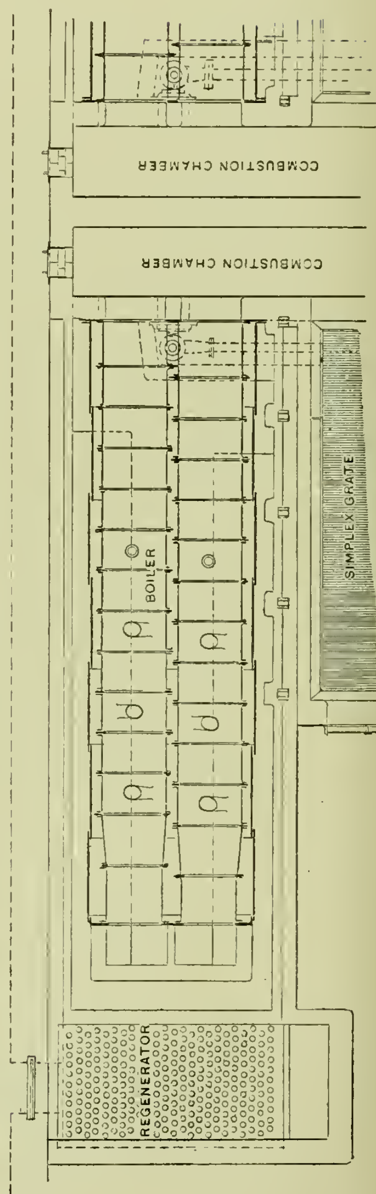


FIG. 527.—Plan of Continuous Regenerator.

foot of grate under normal working conditions, although no difficulty need be experienced in increasing this up to 52 lbs. or 56 lbs. per square foot of grate. If the evaporation per pound of refuse be taken at $1\frac{1}{2}$ lb. of water per lb. at 42 lbs. per square foot of grate, this would give an evaporation of 5,985 lbs. of water per hour, and if the increased rate of 56 lbs. be taken at the same value the evaporation will be 6,175 lbs. of water evaporated per hour.

It will also be interesting to note that if power in excess of this be required and the working pressure is taken at 150 lbs., there is an amount of heat stored in the body of water contained in the boiler, the highest water level being taken within 15 ins. of the boiler crown for 200 lbs. pressure, which heat is given out in the form of steam when reducing from the 200 lbs. pressure to 150 lbs. There is also the heat contained in the water between the highest and lowest water gauge levels, which is at the temperature equal to 150 lbs. pressure, viz., 366° Fahr. This quantity of water will consequently require less heat to evaporate it at 150 lbs. pressure than from the feed. This heat storage may be accumulating during the light load period in readiness for a heavy load period, which, extending over say $3\frac{1}{2}$ hours, would materially increase the evaporation, thus :—

Temperature of water at 215 lbs. pressure, abs..................................388° Fahr.
" " " " 165 " " " ....366° "
Heat units given out due to fall of pressure from 215 lbs. to 165 lbs. abs. = 22.
Maximum total weight of water, lbs. = 46,900
Total heat units given out by water at 215 lbs. absolute, falling to 165 lbs. abs. = 46,900 × 22 = 1,031,800
Extra total heat of iron, 52,180 × ·12 × 22 = 137,637
" heat in brickwork setting.. 137,767

1,307,334

$$\frac{1,337,334}{858} = 1,523 \text{ lbs. extra evaporation.}$$

In addition to this there is the heat stored in the water between the highest and lowest water levels at 165 lbs. pressure absolute, or 366° Fahr., instead of feed perhaps at 160° Fahr., = 20,563 (weight of water) × 200 = 4,112,600 heat units ; 20,563 ÷ $3\frac{1}{2}$ hours = 5,875 lbs. water requiring less heat ; $\frac{5,875 \times 200}{858} = 1,368$ lbs. per hour, where 200 = difference in temperature of feed and water in boiling already heated ; 858 = latent heat of steam at 165 lbs. absolute pressure. Then the evaporation of 6,300 lbs. of water per hour can be increased by the heat and water storage to 8,100 lbs. water per hour.

The few facts and figures submitted indicate fairly conclusively that power can be and is obtained in large quantity from the refuse of towns without sacrificing the efficiency of destruction. That the essential point in the design of such furnaces is simplicity, absence of moving parts, as movable grates, which quickly clog and become unworkable, and a properly designed system of forced draft, which should be self-sustained, and not rely on the working of machinery liable to break down, seems also evident. These points Messrs. Meldrum Brothers claim to have in their types of destructors, and the claim seems to be justified by the figures given.

It has hitherto been customary to place a series of baffle piers in the flue, between the furnace and the chimney, in order to maintain a reserve of heat, but this addition has been found to be quite unnecessary.

A very special feature of the Meldrum destructor is the shortness of the chimney, and, according to Mr. W. H. Maxwell, a height of chimney shaft of 40 feet is said to be ample for the requirements of the Meldrum furnace.

Artificial or Forced Draught for Steam Boilers.—The object of forcing the draught of steam boilers is to obtain a higher rate of combustion of the fuel per square foot of fire-grate surface than could be obtained by natural draught. The amount of coal that can be burnt per square foot varies with the intensity of the draught from 30 lbs. to 200 lbs. per hour, but for a moderate forced draught, from 35 lbs. to 50 lbs. of coal consumed per hour may be taken on an average. The combustion with a forced draught is more complete than with natural draught ; and as the gases are given off at a higher temperature, the efficiency of the boiler is increased.

To develop the same horse-power, a smaller grate area and smaller boilers can be utilised than with natural draught.

The fire should not be less than 10 inches thick, and if allowed to be reduced to 7 inches before stoking a loss ensues through the passage of an excursive supply of air, so that as the intensity of the draught is increased so should the thickness of the fire ; the space between the crown of the furnace and the top of the fire should be rather more than 10 inches. For forced draught to be economical, the heat generated by the combustion of the fuel should be absorbed as far as possible by the heating surface of the boiler ; and for this purpose special arrangements should be made. By the use of artificial draught inferior fuel may be burnt, as it is practicable to arrange a suitable draught, and at the same time to ensure its proper distribution both below and above the fuel in the furnace.

Mr. H. R. Kempe, A.M.I.C.E., in "The Engineer's Year-book," 1898, writes :—" Various methods have been introduced for increasing the draught for boilers by mechanical and other means. This may be accomplished either by creating, by means of a fan or blower, a plenum in the stokehole, which must be made air-tight, or by the easier and simpler method of delivering the air into a closed ashpit under pressure, and thus forcing the air through the fire, as in Howden's system, which gives a pressure ranging from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch.

"The steam jet has, however, of late come very largely into prominence in this connection, and considerable success has been obtained by the Meldrum system, in which the air is delivered into the closed ashpit by means of a steam blower of special construction, which, in conjunction with specially-made bars, spaced only one-sixteenth of an inch apart, is able to utilise coke breeze, coal dust, refuse from coal-washing machine, etc., to great advantage. This furnace renders a high chimney-stack quite unnecessary, as a pressure equal to 3 inches of water can, when necessary, be given by means of the steam-jet blower, which will readily burn any substance that has a reasonable percentage of combustion in it."

Power Required to Drive Fans for Forcing Combustion.—Mr. Walter S. Hutton, in his comprehensive work on "Steam Boiler Construction," states :—"The power required to drive a fan for forcing the draught in the furnace of a steam-boiler may be found by the following formula :—

"Let P = the pressure of the air delivered by the fan in pounds per square foot.

" V = the volume of air at 32° Fahr. in cubic feet used per pound of fuel.

" W = the weight of fuel in pounds burnt per square foot of fire-grate surface per minute.

" A = the area of the fire-grate in square feet.

" T = the absolute temperature of the air entering the fan in degrees Fahr.

" C = the co-efficient of the efficiency of the fans, which varied in practice from ·2 to ·5.

"Then, the indicated horse-power required to drive a fan =

$$\frac{P \times V \times W \times A \times T}{33000 \times (461^\circ + 32^\circ) \times C}$$

"The pressure of the air in pounds per square foot is found by multiplying the pressure in inches of water by 5·196.

"Example :—Required the indicated horse-power of an engine to drive a fan to deliver air at a temperature of 69° Fahr., at a pressure of 3 inches of water ; weight of coal burnt per square foot of fire-grate per hour, 84 lbs. ; area of fire-grate 50 square feet ; air allowed for combustion 200 cubic feet per pound of coal.

"Thus, the pressure of the air is = 3 inches × 5·196 = 15·588 lbs. per square foot; the coal burnt per square foot of fire-grate per minute is $= 84 \div 60 = 1{\cdot}4$ lb.: the absolute pressure of the air entering the fan is $= 69^\circ + 461^\circ = 530^\circ$ Fahr.

"The efficiency of the fan may be taken at ·5, and

$$= \frac{15{\cdot}588 \text{ lbs.} \times 200 \times 1{\cdot}4 \text{ lbs.} \times 530^\circ}{33{,}000 \times 493^\circ \times {\cdot}5} = 14{\cdot}21$$

indicated horse-power.

"If 22 indicated horse-power were developed per square foot of fire-grate surface per hour, then the power of the boiler will be $= 22 \times 50 = 1{,}100$ indicated horse-power, and the power absorbed in driving the fan is $= 14{\cdot}21 \times 100 \div 1100 = 1{\cdot}3$ per cent. of the total power developed."

The Babcock and Wilcox Boiler.—Considerable attention has lately been directed to the best means of recuperating the waste heat in

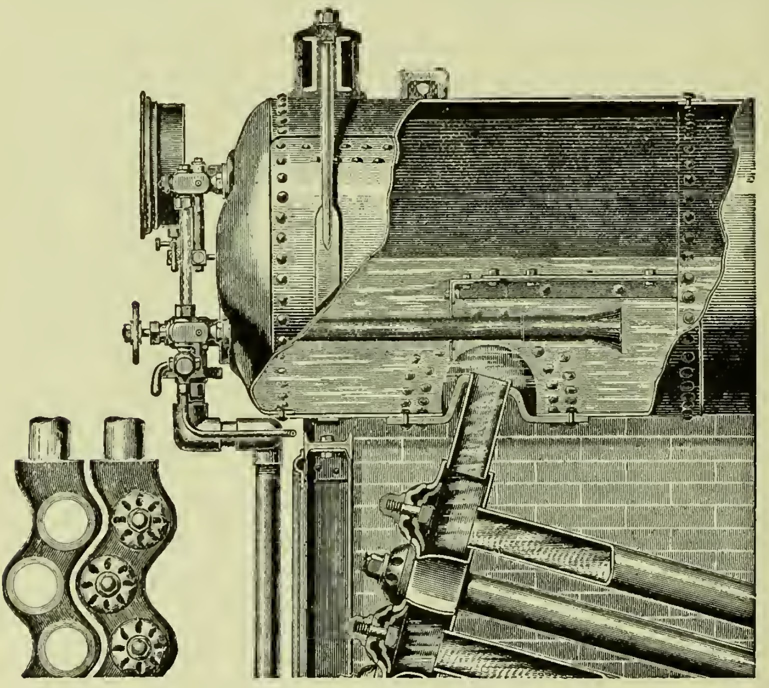


Fig. 528.

destructor gases, and of utilising it for steam-raising purposes, and the general concensus of opinion is, that undoubtedly the best type of boiler for this work is the patent water-tube boiler manufactured by the Babcock and Wilcox Company, an illustration of which is given in Plate LX., facing page 556.

It may be well to explain that in a "water-tube" boiler the water is in the inside of the tubes and the fire on the outside, whereas, in a "fire-tube" boiler, the water is on the outside of the tubes, and the gases from the fire pass through the inside.

The Babock and Wilcox patent water-tube boiler is essentially composed of three parts : the tube sections, steam and water drum, and the mud drum. Sections of this boiler as employed in the Bennett Phythian destructor are shown in Figs. 521 and 522, page 554. The tubes of each section are placed in an inclined position, and are connected in vertical sections with the steam and water drum, which is fixed horizontally, whilst the lowest end of each section of tubes is connected to a mud drum fixed at the rear of the boiler.

The end connections for each vertical row of tubes are in one piece. and are of such form that the tubes are staggered, that is, are so placed that each row comes over the space in the previous row. The holes in the "headers," as the end connections are called, are accurately sized, and the tubes fixed therein by means of an expander. The sections thus formed are connected with the steam and water drum and with the mud drum, by short tubes expanded into bored holes, thus avoiding all bolts, and leaving a clear passageway for the water, between the several parts.

Opposite the end of each tube an opening is arranged for cleaning purposes, these openings being closed by handhole fittings, the joints of which are made in a most thorough manner by milling the surfaces to accurate metallic contact. (*Vide* Fig. 528.)

The handhole fittings are held in place by wrought steel forged clamps and bolts ; no packing of any kind is employed.

The boiler, with the exception of the mud drum, is constructed throughout of mild steel, even the headers being of this material. The steam and water drum is of extra thickness, the longitudinal seams being doubly riveted. All the fittings are specially heavy, and of the most modern design, and this, combined with high-class workmanship, enables boilers of this class to be used for practically any pressure ; and there are many instances where such boilers are in daily use at pressures of over 300 lbs. per square inch.

The British Admiralty have recently installed two similar boilers at their Portsmouth dockyard, to work at 350 lbs. pressure daily. In connection with refuse destructors, however, the ordinary working pressure is from 140 to 160 lbs., although at Shoreditch, where the Babcock and Wilcox boiler is also in use, they work at 200 lbs.

According to the plans ordinarily adopted, the waste gases from the destructors enter the boilers either at the front or through both side walls, somewhat above the ordinary level of the grate bars, thus enabling auxiliary hand firing to be employed when desired. This is an important consideration, particularly if the destructor plant is worked in connection with an electric light station. When the boilers are arranged in this manner, so that the gases come through both side walls, a destructor cell is placed on either side of the boiler.

By this means a large amount of the total heating surface in the boiler is massed immediately above the entrance of the gases ; this ensures not only a higher efficiency, but a far greater evaporative capacity in a given space.

Another point of considerable importance is the very complete arrangements made in the design of the Babcock and Wilcox boiler for a rapid water circulation (whereby all parts of the boiler attain a uniform temperature) and for the free expansion of all the parts. The necessity for free expansion is apparent where boilers have to be fired with any kind of waste heat, the intensity of which may fluctuate rapidly.

An ordinary boiler of the shell type, on account of its rigid construction, and the absence of positive water circulation, must be subjected to heavy racking strains due to unequal expansion, strains which, in the course of a comparatively short time, entail expensive repairs and materially shorten the life of the boiler.

The advantages claimed for the Babcock and Wilcox water-tube boiler are : their safety from disastrous explosion, economy in working and in space occupied, low cost of maintenance, and the fact that all parts of the boiler are readily accessible, and can be inspected during working.

As an indication that these claims are well founded, may be mentioned the fact that the Babcock and Wilcox Company alone have over 25,000 boilers, aggregating over two and a half million horse-power, in use, and the following amongst other destructor works have adopted this type :—Birkenhead, Bolton, Cambridge, Canterbury, Leeds, Leyton, Norwich, The Vestry of St. Leonards, Shoreditch (6 boilers), The South London Electric Light and Destructor Works, Wakefield, Warrington, etc., etc.

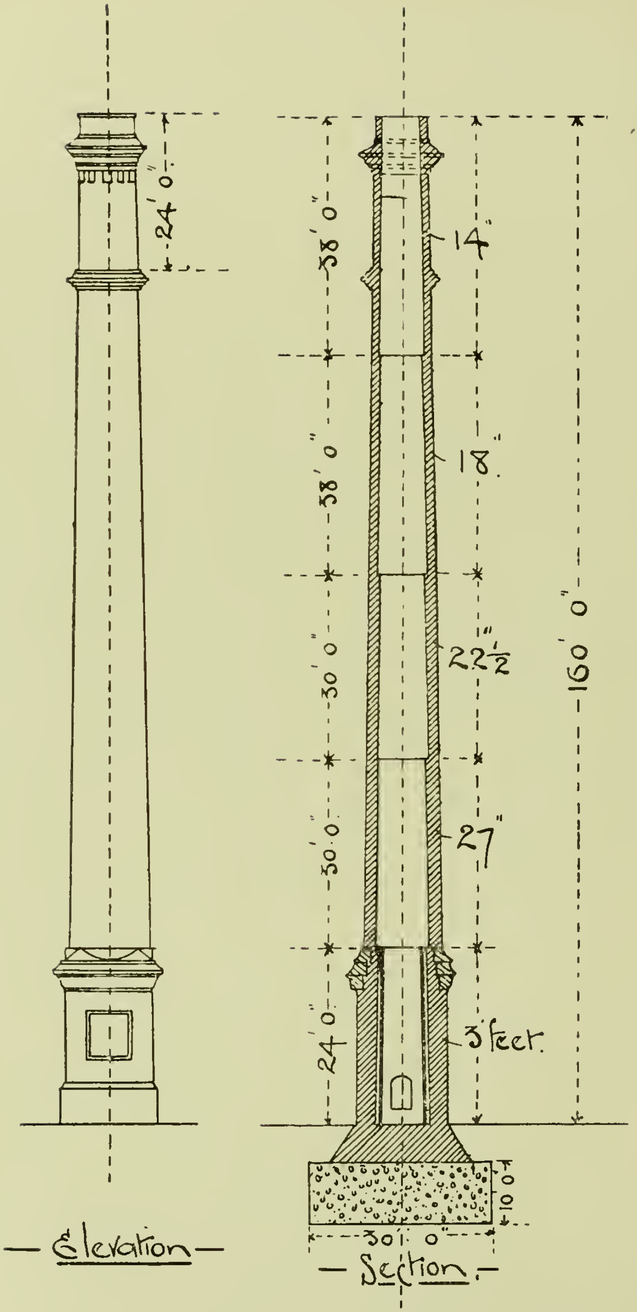
Sewerage and Sewage Disposal Works at Southampton.

The following is a brief description of the sanitary and sewage disposal works carried out in this borough:—

"Early in 1885 the Corporation considered it expedient to introduce a more efficient system of collection and disposal of house refuse, and about the same time they found it desirable to clarify the sewage of a district of the town, which was discharged into the Southampton Water at the Town Quay in its crude state.

"Mr. W. B. G. Bennett, C.E., the Borough Surveyor, was instructed to devise a scheme to accomplish these objects, and accordingly proposed the adoption of Messrs. Manlove, Alliott, Fryer and Co.'s refuse destructor, to serve the double purpose of destroying the ash-bin contents and garbage, and of disposing of the sewage-sludge deposited, in the process of clarification, in two existing reservoirs adapted for the purpose, each 100 feet long and 60 feet wide, and at the lowest end 10 feet deep. Formerly the sewage of a district of the town, amounting to 500,000 gallons in twenty-four hours, from a population of about thirteen thousand, for the most part flowed by gravitation into these reservoirs, from whence it was discharged into the tideway at low water ; whilst a small portion, coming from a low-level sewer, passed through iron pipes, laid under the reservoirs, direct into the tideway. The reservoirs act alternately, one being left still for precipitation of the sewage, whilst the other is being filled.

"In order to render the discharge of the effluent from the reservoirs independent of the tide, and to raise the low-level sewage into the reservoirs for treatment with the rest, two of Shone's pneumatic ejectors were put down, one of 360 gallons capacity, placed below the invert of the low-level sewer, which serves for discharging the sludge as well as for raising the low-level sewage, and the other of 700 gallons capacity placed in the east reservoir. There is also a third ejector of 360 gallons capacity which deals with the sewage of another district of the town near the works, operated also by the destructor, which raises the sewage from a low-level sewer to a higher one about eighteen feet above, the compressed air required being 12 lbs. to the square inch. This ejector was formerly worked by an independent steam-engine, costing for coals about £120 per annum, which is now saved. In each reservoir there is a floating sewage inlet, consisting of a pipe connected with the large ejector and shackled to a buoy, which makes the pipe rise and fall with the water-level, keeping its mouth, which is covered with perforated plate, a few inches below the surface of the effluent, to prevent the passage of any floating matter. Directly the clarification by precipitation has been effected to a certain depth, a valve is opened, admitting the effluent into the ejector, whence it is at once discharged into the tideway. A supplementary sewage outlet is also provided in each reservoir for discharging the effluent by gravitation when the tide is low enough. When the whole of the effluent has been thus drawn off, the buoy, resting now upon the floor of the reservoir, keeps the mouth of the inlet sufficiently high to prevent the admission of any sludge ; and the sludge is then admitted into the ejector by opening a valve, and is transmitted by pneumatic force through a line of four-inch cast-iron pipes, nearly a mile in length, to the destructor erected on the Chapel Wharf. Ferozone, supplied by the International Water and Sewage Purification Company, is used for precipitating the sludge ; it is mixed with clean water into a stiff paste, and led through a shoot into a box with perforated sides, placed in the sewer. The sewage flowing past washes the ferozone gradually out of the box, and is thoroughly mixed with the ferozone by the time it discharges into the reservoirs at a man-



CHIMNEY SHAFT, SOUTHAMPTON DESTRUCTOR WORKS.

hole 150 feet off. A small stream of water falling down on the ferozone prevents its consolidating. The box is filled three times in twenty-four hours, and this method of dosing the sewage has proved quite efficient and satisfactory. A pressure of air forty pounds on the square inch is required for working the sludge ejector, and ten pounds for the effluent ejector.

"The sludge is discharged into a cell, from whence it is drawn as required through a valve-pipe, and after mixture with road-sweepings or sorted house refuse, in an incorporator, is transmitted by a specially arranged conveyor to an elevator, which loads it into trollies, as a good dry portable manure, which has all been readily bought up by agriculturists, since the commencement of the works, at 2*s.* 6*d.* per load delivered at the works, and large quantities of this manure are shipped to the Channel Islands, where it is in great demand, and is used with most favourable results in the cultivation of market produce, which finds a ready sale in the London markets and elsewhere. A 6-H.P. steam-engine drives the incorporator and elevator. On an average sixty cart-loads of ash-bin contents are daily collected and disposed of. Twenty-five tons of refuse, when burnt, generate sufficient steam for the carrying on of the works for one day. The road-sweepings are never burnt. In wet weather the road-sweepings are stored and dried, and the fine ashes from the destructor are incorporated with the sludge in their place; but frequently during the winter, to keep pace with the demand, the sludge is run into bays made of and filled in with road-sweepings, and amounts in twenty-four hours to the amount of about eight tons. Arrangements were provided for burning the sludge. It was discharged into a tank on the floor of the destructor, and drawn out through ports in the front opposite the feed-opening of the cells, where its moisture was absorbed by the ash-bin contents, backed up against the ports with this object, and the mixture was then raked into the fires. Large quantities of sludge have been thus destroyed, but the process has been discontinued owing to the ready sale of sludge when prepared for manure.

"The refuse destructor has six cells, or furnaces, each capable of burning eight to nine tons of garbage per day. The products of combustion pass through a 30-H.P. multitubular steel boiler in the main flue to a furnace shaft, which is of circular brickwork 160 feet in height from the ground line, inside diameter at the top 6 feet, ditto at the bottom 7 feet, constructed upon a pedestal 14 feet 6 inches square and 24 feet in height, of brickwork 3 feet thick, then in 4 sections as follows (*vide* Plate LXA):—

1st in 27-in. brickwork...	... ...	30 feet high.
2nd in 22½-in. ,,	... ...	30 ,,
3rd in 18-in. ,,	... ...	38 ,,
4th in 14-in. ,,	... ...	38 ,,

"The first thirty feet is fire-brick lined, with a cavity of four and a half inches behind, ventilated to the outer side. The lining is steadied by header firebricks, which project sufficiently to touch the common brickwork.

"The foundation is loamy clay, upon which is laid a bed of concrete thirty feet square and ten feet thick.

"The footings commence at 23 feet 2 inches square, and step off in regular courses up to 15 feet square, at a height of 6 feet. The concrete was filled in continuously until completion. The pedestal was then run up and allowed to remain for nearly three months during the winter, after which the works proceeded until completion, which occupied about six months.

"The cap is white brick in cement, with a string course about twenty feet below the top, also set in cement; the remainder of the shaft is built in mortar. This applies also to the footings. No cramps were used in the cap.

"Foot irons are built inside in a winding lead to the top.

"The shaft is provided with a copper tape lightning conductor, with inch rod and crow's-foot seven feet above the cap. The tape is about 215 feet long, the end being carried into a well.

"In August, 1888, the shaft was damaged by lightning, but was easily repaired, owing to the provision of the foot irons referred to. At this time the shaft was plumbed and found to be quite vertical. The fires were only damped down during the repairs, which occupied about eight days. With the exception of this interval they have been constantly burning for nearly four years.

"The repairs have been almost *nil.*

"There is also a by-pass in which a smaller boiler is placed, to enable the works to be continued during cleaning and repairs. No obnoxious fumes from the combustion have been perceived. The steam generated in the boiler is employed for driving a pair of engines, of 31·5 indicated H.P., which compress air into two large receivers, whence it passes in a five-inch main to the Town Quay, where it is automatically supplied to the ejectors when required for working them; and it also serves for driving the precipitated sludge through the main to the destructor before referred to, being led from the receiver by a pipe to the head of the main at the Town Quay, and also the 6-H.P. engine before mentioned, and the engine used in connection with the machinery for the preparation of the horse fodder at the Corporation stables.

"All obnoxious matters are collected throughout the borough in specially-constructed, covered, iron tumbril-carts, which go up the inclined roadway approaches to the destructor, and discharge their contents out into the cells. The road-sweepings are discharged into a hopper over the incorporator, and are mixed with the sludge as required.

"The residue from the continuous day and night combustion consists of about 20 per cent. of good hard clinkers and sharp fine ashes ; the clinkers are used for the foundation of roadways and the manufacture of paving-slabs, which have already been used in paving several footpaths of the town, at a cost of 2*s.* 6*d.* per yard ; the fine ashes are also employed for making mortar, with which the stables and swimming baths have been erected, and for many other purposes.

"The waste heat from the destructor is also utilized for producing electricity. The engines before referred to drive a dynamo sufficiently powerful to feed either ten arc lamps of 3,000-c.p. each, thirty 1,000-c.p., or two hundred glow lamps of the ordinary 16-c.p. type. At the present time the works are lighted with two 3,000-c.p. and twelve glow lamps, and frequently four streets in the vicinity of the works are lighted, but this has only been done experimentally for the information of the Corporation, who have from the successful results obtained unanimously resolved to extend the installation to the municipal offices, the church clock opposite, the Hartley Institution, and the Town Hall at the Bar Gate. For this purpose it is proposed to place accumulators in the basement of the municipal building, to be charged through a cable from the works. This lighting will be more economical than the gas, as it will be seen no cost will be incurred for fuel, as we have ascertained that the house refuse will be sufficient to maintain the steam. In order to show that further use can be made of refuse destructor and the utilization of town refuse in connection with sewage treatment, nothing will be easier than to employ it for the electrical treatment of our sewage ; for we shall only have to place the electrodes in our existing reservoir, and charge them from the dynamos at the destructor works by cable.

"The destructor is also employed in giving a helping hand to a neighbouring authority.

"The Corporation supply the Local Board of Shirley and Freemantle, about two miles from here, with sufficient compressed air to work ejectors which they have put down in connection with the disposal of their sewage sludge after precipitation. The compressed air is conveyed through a four-inch main between the two works, thus saving them the cost of a pumping station, and bringing to the Southampton Corporation a return of £200 a year, which is paid for the compressed air.

"The initial cost of the destructor, including engine house, inclined roadway, chimney shaft and boiler, and ironwork complete, was £3,723 ; and the sewage disposal portion of works about £3,000.

"The annual expense for burning refuse is as follows:—

	Per Week. £ s. d.	Per Annum. £ s. d.
Two stokers, £1 5s. each, one day and one night	2 10 0	182 0 0
One feeder, day only	1 0 0	
Half time of Superintendent		39 4 0
		£221 4 0

"Maximum quantity burnt per day of twenty-four hours is fifty tons, which is less than $3\frac{1}{2}d.$ per ton for burning.

"The minimum quantity burnt per day of twenty-four hours is about twenty-five tons.

"This quantity has maintained the steam for the purpose of our work for twenty-four hours, the indicated H.P. of the engines being 31·5, or ·80 of a ton of refuse per H.P. for twenty-four hours, or seventy-five pounds of refuse per H.P. per hour.

"The annual expenditure for the sewage clarification and disposal works is £308, as follows:—

	£ s. d.
365 days (precipitating material average 8s. 2d. per day)	149 0 0
Labour attendants at reservoirs	65 8 0
Two men at wharf manure mixing	93 12 0
Total	£308 0 0

"The amount received from the sale of manure and supply of compressed air during the last year was £800.

"The products from the destructor, which include the concrete slabs before referred to, steps for police station, clinkers used for concrete foundations, fine ashes for mortar and foundations for footwalks, and clinkers sold for new cycle track, represent about another £300.

"To which could also be added the saving for coal required for working the engines."

Objection has been taken to this system on account of the destruction of the organic matter existing in sewage, which, as it contains nitrogen, phosphoric acid, and potash, is very suitable as a manure, and should, therefore, be employed as such, instead of being uselessly destroyed. However, in spite of all objection to the contrary, the difficulty of the disposal of the sludge is readily surmounted by this process, at any rate on a small scale.

New Scheme of Main Sewerage and Sewage Disposal.—Two years ago the borough boundaries were largely extended, involving an increase of the former area of 2,004 acres to 4,417 acres, and a very large scheme of main sewerage and sewage disposal for the whole borough, at a cost of about £120,000, is now being carried out in accordance with the designs prepared by Mr. W. B. G. Bennett, C.E., the Borough Engineer and Surveyor.

Under this scheme the works of sewage disposal, already described, in several districts of the town, will be abolished, and the whole volume of sewage of the borough brought to one point for disposal.

It has been found necessary to re-sewer the whole of that portion of the old borough known as the Eastern or Belvidere District,* for the following reasons, as stated by Mr. Bennett :—

" The principal one is that hitherto the sewage of a district comprising upwards of 500 acres, having a population of over 40,000, has been discharged into the River Itchen untreated. This state of things can no longer be tolerated in a town like Southampton, and therefore works are being carried out to intercept the sewage and treat it before it enters the river ; many of the present sewers lie at much too low a level compared with the tide. Consequently, at high water it has been found difficult to discharge them. It is, therefore, imperative that a new set of sewers shall be laid, in such a manner as will permit of discharge at any state of the tide.

" Many of the sewers also are too large, and at one place the sewer is quite seven feet high inside, and wide in proportion, which is absurdly large for the normal flow at that point ; the formation of sewer-gas in the meanwhile goes on at a rate which converts the sewer into a veritable gas retort. The new sewers are designed to give a good velocity throughout.

" The greater part of the old sewers will be retained, and utilised for rainfall drainage only. The advantage of this is that the quantity of fluid to be chemically treated is at once reduced, for there remains in the soil sewers only what is termed ' the dry weather flow,' plus a certain amount of unpreventable rainfall, such as will find its way into the soil-pipes from yards and the back roofs of houses. The storm-water requires no treatment, and it will be sent into the river direct.

" Another reason for re-sewering is that we want to prevent a recurrence of the constant flooding of the basements in the lower districts at times of heavy rainfall, and, further, to provide an efficient system of ventilating the sewers and preventing the formation of sewer-gas.

" The positions of the main sewers constructed and in course of construction for the purpose of preventing the pollution of the river Test on the west, the river Itchen on the east, and the Southampton Water on the south, are shown on Plate LXb., facing page 582. It will be noticed that the town is nearly encircled on its water faces by the intercepting sewers, which have been so placed with the object of intercepting all existing sewers at present discharging into the tide at the outfalls now being

* The new egg-shaped sewers and circular pipes are illustrated on Plate XIa., facing page 232.

abandoned, as marked on the Plate. These intercepting sewers are also the outfalls for the new sewers being constructed under the scheme, and are marked A.A.A., B.B.B.B., C.C.C., D.D.D.D., on the Plate. A.A. is a main sewer which passes under the highest part of the town by a tunnel, its purpose being to transmit the sewage of the western districts received by the sewers D.D.D.D. to the new outfall on the East Market, H., in place of those abandoned. A portion of the sewage on the extreme west will not gravitate ; it is therefore raised at the point E. by two of Shone's pneumatic ejectors, and discharged into the head of the remaining portion of the D.D. sewer. The same difficulty is overcome as regards the district of Northam on the east by the ejector at G. Again, a portion of the sewage received into the sewer C.C. has to be treated in a similar manner by the ejector at F. The whole volume of the sewage of the borough will therefore, under this scheme, by means of the sewer and ejectors referred to, be discharged at one outfall, H., in place of at the four which at present exist.

"Starting from Chapel Wharf, new egg-shaped sewers (see Figs. 1—4, Plate XIa., facing page 232) are being laid in a very durable style. On a concrete foundation is placed an invert-block of Staffordshire blue brick, on which the invert is built of similar material. The remainder of the sewer is of hard, purpose-made red bricks, laid in cement. The dimensions of the first section, which passes along Wharf Street, Elm Place and Chapel Road, are 4 feet 6 inches × 3 feet. Joined to that will be a section of 4 feet × 2 feet 8 inches, going along Granville Street and Melbourne Street to Bevois Street, where a length measuring 3 feet 6 inches × 2 feet 4 inches will commence. Then passing under the approach to Northam Bridge, and ultimately under the railway, will be a thirty-inch cast-iron pipe (Fig. 8, Plate XIa.), whilst from thence the sewer will be continued in the form of twenty-four-inch stoneware pipes, which will go along Derby Road as far as Mount Pleasant. There it will connect with the existing drains from Bevois Town, Newtown, and part of the Valley. These are the arterial or main sewers, which are now being proceeded with in the eastern district. In the St. Mary's district there is great difficulty to cope with in the matter of tidal-locking. The new sewer for this district will commence from the large egg-shaped one already described, and will pass along Chapel Road, under the railway, and terminate at the top of St. Mary's Street, near the railway bridge. It will be of stoneware, starting at eighteen inches diameter, and diminishing three inches at a time to twelve inches.

"Another section of the new sewers is to be laid along Marine Parade and Belvidere Road, and the object of this is to intercept the drainage of water-side premises, so that in future no soil drainage shall be discharged into the river, untreated, at that point. In the main scheme the district of Northam is perfectly dealt with, and as that district lies very flat, it has been deemed advisable to treat it, in a sense, as a separate area. In accordance with this plan two of Shone's ejectors are being put down in Rochester Street, at a depth sufficient to allow of the sewers for that locality to discharge into them with good gradients. This renders Northam also independent of the tidal influences already referred to. The purpose which the ejectors will fulfil will be to lift the sewage from the low-lying spot where they are placed and send it along to Chapel Wharf.

"At Chapel Wharf the big sewer passing through the boundary wall empties its contents into two pump wells, or rather one of them; hatches are provided by which it can be directed into the wells alternately. Each well has a screen to keep the suction-pipes of the pumps clear of obstructive matter.

"The new engine-house is close by, and in it are three compound condensing Worthington sewage-pumping engines, each guaranteed by the makers to empty the wells at the rate of 2,200 gallons per minute. One of these will suffice for the night-time, when the flow is very small; two will probably be kept on during the day, and the third is there to meet an emergency. They will lift the sewage twenty feet and discharge it into the mixing culvert. This is next the engine-house, and at one end is the chemical store. Here the sewage is dosed with the chemicals, and then it is made to pass through two steam-driven mixers.

"The exact nature of the precipitating agent to be employed has not yet been finally decided upon. The mechanism of the mixers consists of what may be termed 'fan-wheels,' which will revolve with great rapidity. From these the sewage will go to the precipitating tanks.

"The tanks are now completed. There are six of them, each having an area of 60 feet × 50 feet, and a depth for sewage of about 6 feet 6 inches. The sewage will be allowed to remain quiescent in them until the chemicals have done their work and all solids have settled. Then the effluent will be drawn away in the form of what it is believed will be perfectly clear water, and the tanks are at such a level that the discharge can take place at any state of the tide. All the tanks are interchangeable — that is, some can be filling whilst the others are full and the remainder discharging or empty for the removal of the sludge. The volume of sewage which will have to be dealt with, taking the dry weather flow, is two and a half million gallons daily.

"Each tank is fitted with a floating arm. When precipitation is going on, a scum forms on the top of the water, and the object of this arrangement is to prevent the scum being drawn off with the effluent. The out-take is always well below the scum, and immediately the solids at the bottom are reached the outlet is automatically stopped. The tanks are uncovered to permit of the whole operation being carefully watched, and at the point where the effluent proceeds on its way to the river an inspection chamber has been constructed, lined with white glazed bricks, where any one may at any time see the sort of liquid sent into the river.

"Before the sludge goes to the presses it is discharged into a reservoir where it is again chemically treated, and the top water is drawn off by a floating arm arrangement similar to that already described, and sent back to the tanks for further precipitation. This reduces to a minimum the odour emanating from the sludge.

"The sludge is drawn from the bottom of the tanks through independent valves connected with a sealed main which leads to two of Shone's ejectors, placed below the invert of the tanks. The ejectors lift it and send it along to the building which has been erected for the sludge presses. These are worked by compressed air, and they reduce the sludge to cakes measuring thirty-six inches square and an inch thick, which are stacked and air-dried. They are then ready for sale as manure, or may be put into the refuse destroyer and burnt.

"To operate the ejectors before-mentioned, a pair of steam-engine air compressors have been erected in a new engine-house at the Corporation Wharf. These compressors consist of a pair of horizontal condensing steam-engine compressors, with air cylinders twenty inches diameter by twenty-four inches stroke, arranged so as to work either independently or coupled together, each of the compressors being capable of doing the whole work if necessary. The air cylinders are fitted with Shone and Ault's patent low lift annular valves, both for the inlet and outlet air, which give a large area for the passage of the air with a very small movement of the valve. The air cylinders are fixed on the same bedplate as the steam cylinders, being placed behind them tandem fashion. The air is thoroughly cooled during compression by water jackets round the air cylinders. The steam cylinders are fitted with variable expansion valves, so that a high degree of economy in steam consumption is obtained.

"For the sludge pressing, a pair of compressors have been provided capable of supplying air at 100 pounds pressure per square inch. These compressors are of the same type as the others, but with air cylinders nine inches diameter by fourteen inches stroke, also arranged to work coupled together, but each is capable of doing the maximum work alone when necessary.

"At Portswood Farm one ejector is in operation to raise the sludge from the tanks on to the irrigation farm, and one ejector to lower the level of the subsoil water and to discharge the effluent; to operate these two ejectors, a small pair of steam-engine air compressors have been put down at the farm.

"The air-compressing machinery, Shone ejectors, and air mains are being supplied and erected by Messrs. Hughes and Lancaster.

"The whole of the steam-power required to drive the pumping engines, air compressors, etc., will be obtainable from boilers fixed in the newly-enlarged refuse destructor at H., and hundreds of pounds which would otherwise be spent in fuel will thus be saved. The works will be completed shortly, and will be gradually brought into operation as each section is finished.

"As regards the western district, the precipitating tanks constructed some years ago at Blechynden for the treatment of the sewage of the western district have, through the rapid development of the district, become quite inadequate to meet the demands made upon them. Shirley and Freemantle are, of course, already sewered, but there are 1,000 acres in Millbrook, Coxford, Shirley Warren, Old Shirley, and Berrywood, now part of thc borough, having no system of drainage at all. It has been decided, with the sanction of the Local Government Board, to sewer that district, and tenders for the first portion of the work have just been accepted by the Corporation. This section will, therefore, be commenced immediately, and it will include Berrywood, the site of the new isolation hospital at Mousehole, and Regent's Park. This new sewer will be connected with the present Freemantle and Shirley system, and the sewage for the whole of the district will be brought to Chapel Wharf and treated with that from the old borough. Two ejectors will have to be put down near Millbrook Station, to lift the sewage at that point, and these will for a time be worked by air compressors driven by two gas-engines. It is intended to eventually construct a refuse destructor somewhere near there, and power will then be obtainable from that to drive the air-compressing machinery.

"From Blechynden to a point just below Manchester Street the sewage will proceed by gravitation through a tunnel to be cut through the high ground under Above Bar Street and Sussex Place to South Front, and then it will run into the new egg-shaped sewer in Melbourne Street, and so on to the wharf. There will be no outlet at all in the western district, and the new arrangement will contribute not a little to the purification of the Western Shore. This part of the scheme will cost upwards of £45,000.

"There is still another section of the scheme, as the sewage of about 13,000 persons, living in High Street and Above Bar, as far as Bedford Place, and in the neighbourhood of the Western Shore, now goes into precipitating tanks at the Platform. It is proposed to divert that also to Chapel Wharf by means of a cast-iron pipe, so that there will be only one outfall instead of four. The advantages of this are obvious. In the first place, instead of treating the sewage at five different places, necessitating five sets of disposal works and their attendants, only one staff will be required, and the working of the whole scheme may be put into the hands of a competent superintendent, who will be held directly responsible for the quality of the effluent which is sent into the river.

"The sewage will be lifted from the wells by compound condensing Worthington pumping engines, designed and manufactured by Messrs. J. Simpson & Co., Limited, who have now for a very large number of years devoted special attention to the development of high-class pumping machinery.

"The engines, of which at the present time three have been erected, will be each capable of lifting 3,000,000 gallons of sewage per day of twenty-four hours into the effluent channel.

"To each engine there are four steam cylinders, namely, two high and two low pressure cylinders, arranged side by side, and the valve gear is so adapted that in operation the piston rod of one side moves the steam valves on the cylinders of the other side, when the pistons of the latter gradually begin to move, and finally attain full velocity as those of the first gradually come to rest, the action of the reciprocating parts of one side blending into that of the other as each alternately takes up the load, the result being that the flow of the suction to and the discharge from the pumps is uniform and constant.

"The main pumps are of special construction for pumping sewage, and their valves and general arrangement of pump work such as is most suitable for that purpose. They are internal plunger pumps, double acting on both suction and delivery, and consist of two distinct plunger chambers arranged in one pump-case with the plungers coupled direct to prolongations of the piston rods, whereby great rigidity between the motive force in the steam ends and the resistance in the water ends is secured.

"Steam is supplied to the engines from the 'destructor' boilers.

"In a corner of the engine-house space has been provided for a small engine to drive the mixers.

"The four additional cells fitted to the refuse destructor are now working, and they contain two new boilers of the water-tube type. The new sewers are to have automatic flushing chambers, and where necessary, ornamental iron upcast ventilating shafts will be provided.

"The precipitating tanks have been constructed; and another feature of the new works at the wharf is the fixing of camp-sheeting along the water side, which will provide capital berths for vessels such as come to the wharf with cargoes of stone. Thus the value of the Corporation's water-side property is being augmented to a considerable degree; and in filling up the space between the edge of the old wharf and the new


SOUTHAMPTON MAIN SEWERAGE WORKS.
References.
A.A.A. New Sewer Constructed in Tunnel under Town.
B.B.B.B. New Intercepting Sewer for Eastern District.
C.C.C. New Cast-iron Sewer for Intercepting Sewage from West Bay District and Town Quay.
D.D.D.D. New Intercepting Sewer for West End Districts.
E.F.G. Shone's Ejectors for raising Sewage from Low-lying Districts.
H. Position of New and only Outfall, also Sewage Disposal Works, Refuse Destructor and Main Pumping Station.
I. Ejectors for Emptying Storm Water Tanks.
OLD SHIRLEY
MILLBROOK
FREEMANTLE
No 12
WARD
SEVERAL SMALL OUTFALLS ABANDONED
EXISTING OUTFALL ABANDONED.
EXISTING OUTFALL ABANDONED
EXISTING OUTFALL ABANDONED
NEW OUTFALL IN PLACE OF THOSE ABANDONED
EJECTOR
EJECTOR
EJECTOR
RIVER TEST
Centre of Stream
RIVER ITCHEN
Millbrook Marsh
High Water Mark of Ordinary Spring Tides
ROYAL PIER
TOWN QUAY
Empress Deep Water Open Dock
Close Dock
Open Dock
NEWTOWN WARD
BRINTONS ROAD
POLYGON
WEST PARK
EAST PARK
LONDON

camp-sheeting, a quantity of clinkers, etc., which have come out of the refuse destructor, are being put to a very useful purpose.

"It may be mentioned that the following contracts have been let by the Corporation in relation to the new works:—Engine-house and pumping wells, sludge-compressing and air-compressing house, Messrs. Jenkins and Son; precipitating tanks, Messrs. Playfair and Toole; pumping machinery and engines, Messrs. Simpson & Co.; air-compressing machines and ejectors, Messrs. Hughes and Lancaster; main sewerage, Mr. George Bell; Derby Road section, Mr. F. Osman; storm-water drainage, Messrs. W. H. Saunders & Co.; Western District sewerage, Mr. F. Osman; camp-sheeting, Corporation Wharf, Messrs. Roe and Grace; sludge presses by Messrs. Manlove, Alliott & Co.

"The sewage from Portswood will continue to be treated by chemical precipitation and land filtration at the Portswood Sewage Farm, where considerable improvements have lately been carried out, whilst others are still proceeding. The tanks which were provided twenty-five years ago by Alderman James Lemon, C.E.—then the Borough Engineer—for the chemical treatment of the sewage, have now been brought into operation, and after the chemicals have done their work the effluent is sent over the land into the river.

"The now small district of Bitterne Park is provided for on the other side of the river, where a precipitating tank has been constructed, and its working is supplemented by irrigation. Eventually, as the district increases, a syphon will probably be laid under the river and the sewage conveyed in it to the sewage farm. A refuse destructor on the Bennett-Phythian principle is now in course of erection at the sewage farm, and whilst this will greatly facilitate the work of refuse disposal in the neighbourhood, a boiler placed in the destructor will cause the coal bill which now comes to the Finance Committee periodically from the farm, to disappear."

Combined Electricity and Dust Destruction Undertaking, Borough of Shoreditch.*—The novelty in this scheme is the combination of refuse destruction with electric lighting, the arrangements being elaborated in such a manner as to suit each other, and the utilisation of Mr. Druitt Halpin's system of feed thermal storage. Electric lifts and motor cars for revising and distributing the refuse throughout the cells are substituted for the usual inclined road and tipping platform, thus effecting a considerable economy in horseflesh. "The steam requirements of the electric lighting station at the same time are treated as of

* I am enabled to include this description by the kind permission of Messrs. Kincaid, Waller, and Manville, consulting engineers to the Shoreditch Vestry, under whose supervision the works were carried out.

secondary importance in comparison with the hygienic manipulation of the refuse."

Shoreditch is a Parliamentary borough in the East Central district of London, with an area of a square mile and a population of 124,000, very densely populated, with the large proportion of 35 per cent. of artizans—the highest percentage in London. It contains in its southern portion (Moorfields ward) a large number of City warehouses and manufactories, forming the recognised centre of the woodwork and furniture industry of London, and offering a splendid field for the sale of electric light and power. The exceptionally large number of public-houses, amounting to 300, and the number of small shops which keep open late at night, make the district one of the largest light-consuming districts in London.

Mr. E. Manville, M.I.E.E., was engaged as consulting electrical engineer to carry out the scheme.

The whole of the dust-destructor and steam-generating plans were designed under Messrs. Wood and Brodie's patents, and were erected by Messrs. Manlove, Alliott & Co., Limited.

The buildings erected consist of a destructor-house and engine-house, with suitable offices, pump and fan-room, and accumulator-room. The engine-house is 68 feet long and 46 feet wide, and is arranged with the high tension continuous current sets on one side, and the low tension sets and station motor transformers on the other side. A gallery of ample width is provided against one wall of the engine-house to accommodate the three switch-boards.

Off the engine-room is a test-room, in which are erected all the testing instruments, and which, in addition, is used for the calibration of meters.

In order to prevent, as far as possible, vibration from the running of the engines, the whole floor of the engine-house has been made a solid mass of concrete, about 10 feet in thickness, and the surface has been tiled. The destructor-house is 80 feet square and contains 12 cells, each having 25 square feet of grate-area, and 6 water-tube boilers, each with 1,300 square feet of heating surface. The cells are charged by means of Boulnois and Brodie's patent charging trucks, and it is possible for one man to keep the whole of the 12 cells charged at regular intervals; and, moreover, the refuse is never left to ferment or heat on hot brickwork or ironwork, but is kept cool and thoroughly well ventilated by artificial draught. The forced blast in the cells may be procured either by motor-driven fans or by the agency of steam jets.

The gases from the cells pass out of each cell at the front, thence through the boiler tubes and out at the back of the boilers into either of the two main flues leading to the settling chambers and chimney.

Whenever required, each boiler may be shut off by means of dampers, entirely free from each or both of its adjacent cells, and may also be fired at all times independently with coal or any other suitable fuel. The cells may also be worked independently of the boilers, but in this latter contingency the gases pass out from the cells at the back and not at the front. Owing to this arrangement, the cells may be repaired independently of the boilers, and the boilers may be repaired independently of the cells ; moreover, in the event of refuse not being collected or being deficient, from any cause whatsoever, steam may still be raised in the same manner as is adopted in any other electric lighting boiler-house, viz., by means of coal, fire-grates being provided underneath the boilers for this purpose. It was anticipated that the most efficient rate of working would be between 8 and 12 tons of refuse per cell per diem.

There are 3 motor-driven fans, calculated to deliver each 8,000 cubic feet of air per minute, with a maximum ash-pit pressure of 3-inch water. The chimney is 150 feet high and 7 feet internal diameter at the top, jacketed with fire-brick throughout, and surrounded at the base with a centrifugal dust-separating chamber.

The boilers and thermal storage vessel are designed to work at a pressure of 200 lbs. per square inch, and are supplied with duplicate fittings throughout, to guard against a breakdown. As it is necessary to burn the refuse continuously during the 24 hours, whereas light on a large scale is only used for some 4 to 6 hours out of the 24, it is necessary to adopt a system of heat storage to avoid a waste of valuable steam.

At Shoreditch, during the daytime, steam generated in the boilers is passed into a thermal storage cylinder (which is 35 feet long and 8 feet in diameter), where it is mixed with a small quantity of cold water from the feed-pumps ; the proportions being such that when the evening approaches, the cylinder is full of water at a temperature and pressure of the steam required by the engines. The cylinder is then shut off from the feed-pumps and connected to the boilers, which in their turn are connected direct to the engines ; hence, when the boilers require feed-water, they are supplied with it from the cylinder at such a temperature that the fuel that is then being burnt has merely to furnish to the water in the boilers the heat sufficient to overcome the latent heat of evaporation at the required pressure. The result of this arrangement is that the boilers are able to evaporate about one-third more steam than they would be able to evaporate were they connected directly with the water mains, and, moreover, gases can be sent away from the boiler at such a low temperature that they would be useless for the purposes of even an economiser.

The importance of the thermal storage cylinder is further enhanced by the fact that it acts as a water purifier.

One of the main drawbacks to the use of water-tube boilers has always been overcome by the use of clean or softened water, but if the feed-water be first raised to 350° Fahr. in the thermal storage cylinder, practically all the inorganic salts held in solution in the water will be deposited there, and water free from these impurities will be delivered to the boiler.

By the addition of complete steam storage, the station as erected in the first instance could probably be run without the use of coal at all, but with feed-storage only it is contemplated that a certain amount of coal will be burnt from the commencement.

The electric work has been carried out by the Electric Construction Company of Wolverhampton. The plant at present installed in the generating station consists of 3 E.C.C. generators coupled to Willans' three-crank engines, each set having an output of 160 kilowatts at about 1,100 volts ; and 3 E.C.C. low-tension dynamos coupled to Willans' three-crank engines, each set having an output of 70 kilowatts at 165 volts. The speed of the larger sets is 350 revolutions per minute, and the speed of the smaller sets 460 revolutions per minute.

The Willans' engines of both sizes have been specially arranged with automatic expansion gear, so that economical results and good governing are obtained when working at any pressure within the wide range of 200 lbs. to 120 lbs. to the square inch ; this range of pressure being necessary in order to enable the thermal storage system to be utilised in connection with the scheme.

The public lighting as at present arranged for consists of 57 standards, supporting arc lamps, replaced by incandescent lamps after midnight, and 36 incandescent lamps in by-streets burning all night.

The system of using arc lamps burning until midnight only, and each arc lamp replaced after midnight with two 32-candle-power incandescent lamps, was originally recommended by the same engineers at Portsmouth ; and the success it has met with there induced the Vestry of Shoreditch to adopt the same method. Owing to the economy effected in the consumption of current between midnight and dawn, the arc lamps will be of a rather larger size than those generally used, namely, 12½ ampères at 45 volts.

These lamps are arranged in circuits of 19 in each series, running off the higher tension bus bars at a difference of potential of 1,000 volts.

The standards supporting the arc lamps are also provided with two brackets supporting the two 32-candle-power incandescent lamps referred to.

Each lamp-post is fitted up with a cutting-in and cutting-out switch, and with one of Messrs. Glover and Company's (Edmunds') patent automatic switches for controlling the lighting of the incandescent lamps.

These switches, which have been used quite successfully at Portsmouth for some time, are so arranged that, during the time of running the arc lamps, should any one arc lamp or the whole circuit be accidentally extinguished, the incandescent lamps are automatically connected up to the low tension network, whilst immediately the lamps in question or the series are re-lighted the incandescent lamps are at once extinguished. At twelve o'clock, when the arc lamps are permanently turned out, the incandescent lamps are lighted automatically by these switches and remain so until the morning, when, by momentarily reversing at the generating station the direction of the arc light current through the arc light circuits, these automatic switches extinguish the incandescent lamps for the daytime. Immediately the arc lamps are lighted again the next evening the switch is automatically put in position to light the incandescent lamps again, should any accident happen to the arc lamps as before described.

The arc lamps themselves are of the Brockie Pell type, double carbons, by Johnson and Phillips, as is also the ornamental carrier carrying the lamp. The lamp columns were supplied by Messrs. Walter Macfarlane and Company, of Glasgow.

The total saving estimated to be effected by the combined schemes is over £3,000 a year.

Results obtained at Shoreditch.—Full particulars of the results obtained cannot be given, as the final tests have not yet been taken. This is mainly due to Mr. Druitt Halpin's thermal storage vessel not yet being in working order, so that no further development in the latter direction is contemplated at present.

The amount of refuse burnt per cell is about ten tons per day, its calorific equivalent value being about ten tons of refuse to one ton of coal.

No coal is used with the refuse, and it is found that the refuse is sufficient to raise all the steam required up to a load of about 300 kilowatts, though much more could be generated during the day if required.

The average indicated horse-power is about 500, and the power used by forced draught is represented by 150 volts and 80 ampères, but varies very considerably.

The cost of burning, leaving out the repayment of capital and interest, is about 2*s.* 3*d.* per ton. This rather high cost is due to the employment of three eight-hour shifts, and other advantages that labour enjoys under municipal employment. There is no doubt but that this cost will be considerably reduced, as, in the initial stages of an undertaking such as this, many improvements are being made from time to time.

It may also be of interest to state that fifteen months after the undertaking had been established the Lighting Committee received applications for no less than 36,000 8-candle-power lamps.

I am indebted for the above information to the courtesy of Mr. H. E. Kershaw, the Chairman of the Committee.

Chimney Shafts—Object of.—The object for which a chimney shaft is built is, in the first place, to produce a draught through the fuel or on the fire-grate, to ensure the combustion of a specified amount in a given time; in the second place, its height should be sufficient to carry off the products of combustion to such a level above the neighbourhood as to avoid creating a nuisance. This particularly applies to chimney shafts for destructors.

The draught in the chimney is caused by the difference in weight of the heated gases inside the chimney and the corresponding column of air outside the chimney. This difference in weight is principally due to the expansion of the gases passing up the chimney, produced by heat; they are thus considerably lighter than the external air, which therefore seeks to penetrate through every available opening, both below and above the fire-grate. This produces a velocity of efflux, after making a deduction for friction, due to the difference in weight of the two columns.

The draught in a chimney is thus obtained by a considerable expenditure of fuel, amounting to as much as from 20 to 30 per cent. of the coal burnt.

Where inferior fuel is employed, as in the case of destructors, increased draught is necessary. This involves an increased height of chimney shaft.

Dimensions of Chimneys—General Rules.*—"The outside diameter at the ground level should not be less than one-tenth the height, unless it is supported by some other structure.

"The batter varies from 1 in 60 to 1 in 10; 1 in 24 is very common. Or the batter should be from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot on each side.

"The thickness of brickwork is generally one brick (8 or 9 inches) for 25 feet from the top, increasing one half brick (4 to $4\frac{1}{2}$ inches) for each 25 feet from the top downwards. If the inside diameter exceeds 5 feet, the top height should be one and a half brick thick, and if under 3 feet it may be one-half brick thick for 10 feet.

"Generally, a much less height than 100 feet cannot be recommended

* Extracted from "The Engineer's Year-Book for 1898," by H. R. Kempe, A.M.I.C.E., M.I.E.E. (Crosby Lockwood and Son).

for boiler chimneys, as the lower grades of fuel cannot be burned as they should be, with a shorter chimney. Tall chimneys should always stand alone; for if connected with the rest of the buildings, the increased settlement due to their height causes rupture in the masonry. The distance from the furnace to the shaft should not exceed two-thirds the height of the shaft, and the latter should be built and allowed to settle before the connecting-flue is made.

"The circular form of chimney is best, as, with the same quantity of material, it covers a greater area, and is therefore more stable, and the effect of wind upon it is much less. In any case, the flue should be circular; it can hardly be too large, as it can always be reduced by dampers. It should be built with a detached skin of firebrick for a certain distance up, increasing in proportion to the heat of the vapours carried off, and separated from the main shaft by an air space.

"Chimneys to receive vapours of a very high temperature are built altogether of fire-bricks.

"The caps are intended to tie the head of the chimney together, but projecting caps catch the wind, and increase the oscillation; a dangerous chimney has been saved by removing the cap.

"The scaffolding used for building a chimney should be so arranged that it does not prevent the chimney from settling.

"The intensity of draught required varies with the kind and condition of the fuel and the thickness of the fires. Wood requires the least, and fine coal or slack the most. To burn anthracite slack to advantage, a draught of 1½ inch of water is necessary, which can be attained by a well-proportioned chimney 175 feet high.

"The effective area of a chimney for a given power varies inversely as the square root of the height. The actual area in practice should be greater, because of retardation of velocity due to friction against the walls. On the basis that this is equal to a layer of air 2 inches thick over the whole interior surface, and that a commercial horse-power requires the consumption on an average of 5 lb. of coal per hour, we have the following formulæ:—

$$E = \frac{0{\cdot}3\ HP}{\sqrt{h}} = A - 0{\cdot}6\sqrt{A} \quad (1) \qquad HP = 3{\cdot}33\ E\sqrt{h} \quad (2)$$

$$S = 12\sqrt{E} + 4 \quad (3) \qquad D = 13{\cdot}54\sqrt{E} + 4 \quad (4)$$

$$h = \left(\frac{0{\cdot}3HP}{E}\right)^2 \quad (5)$$

In which HP = horse-power; h = height of chimney in feet; E = effective area, and A = actual area in square feet; S = side of square chimney, and D = diameter of round chimney, in inches.

"Another rule is the following :—
A = least internal area of flue, in inches.
a = area of grate, in feet.
HP = horse-power of boiler.
h = height, in feet, of chimney from fire-grate.
P = pounds of coal consumed per hour.

$$A = \frac{112 \text{ HP}}{\sqrt{h}} = \frac{12 \text{ F}}{\sqrt{h}} \text{ (Tredgold)}$$

F being in this case = 9·33 HP, or 9·33 lbs. per HP hour.

"A common rule is to make the flue and area of the chimney top equal to from one-eighth to one-tenth the area of the fire-grate, without taking into account the height of the chimney.

"To find the draught of a given chimney in inches of water, we have

$$d = h\left(\frac{7·6}{t_a} - \frac{7·9}{t_c}\right)$$

where h = height of chimney, in feet, t_a the absolute temperature of the external air = $t + 460$, and t_c the absolute temperature of the gases in the chimney = $t^1 + 460$.

"To find the height of a chimney to give a specific draught-power, expressed in inches of water, we have

$$h = \frac{d}{\dfrac{7·6}{t_a} - \dfrac{7·9}{t_c}}$$

"To find the maximum efficient draught for any given chimney, the heated column being 600° Fahr. and the external air 62°, multiply the height above grate in feet by ·007, and the product is the draught-power in inches of water."

Where two flues are led into one shaft, a partition wall should be erected across the shaft and carried up to double the height of the flues, so as to bend the currents in the same direction.

Average Height and Cost of Destructor Shafts.—Mr. Boulnois states that the average height of chimney is 163 feet, and that the average cost of erection is £6 3*s.* 4*d.* per foot.

Foundations for Chimney Shafts.—The foundations of a building are usually considered to include all the parts below the surface of the ground which are put in for the purpose of carrying the weight of the superstructure ; ground on which those parts are built is termed the foundation-bed.

The best foundation-bed would be an incompressible material, free from water, and of such extent and thickness that it will not yield under the pressure to which it is to be subjected; the ground to be built upon should be homogeneous.

These conditions cannot ever be absolutely fulfilled, and therefore foundations should be arranged in such a manner as to ensure the settlement, which always takes place more or less in all engineering works, being uniform.

Professor Rankine gives 2,500 to 3,500 lbs. per square foot as a safe load to be put upon a firm foundation-bed, such as hard clay, dry gravel, or clean dry sand; however, in many instances of existing buildings in London, as much as 5 tons per square foot is safely carried on gravel and on London clay.

In the case of rock the intensity of the pressure on it should not exceed at any point one-eighth the crushing strength of the rock. The following are considered safe loads for ordinary rock foundation-bed :—

	Tons per sq. foot.
Rock moderately hard, strong as the strongest red bricks ...	9·0
Rock of the strength of good concrete	3·0
Rock of a very soft, crumbly nature	1·8

The bearing power of most solid rocks is, however, far in excess of any weight which in ordinary buildings can be put upon them, but great care must be exercised on rocky sites in bridging over soft dykes or fissures with concrete, as otherwise, unequal settlement will occur.

Table 95, of safe maximum loads for various soils, is given by Mr. Newman in his work entitled "Earthwork Slips and Subsidences."

In order to ensure equal settlement the bearing surface on the foundation-bed should be extended until a uniform pressure, not exceeding the amount the special nature of the ground will bear, is attained.

The position of the bearing surface should be as nearly as possible perpendicular to the pressure, and the lateral escape of the supporting material or foundation bed should be prevented.

With these objects in view, the foundation-bed should be levelled or cut into horizontal steps, and if the ground is soft it may be necessary to retain it with short piling round the site, and even to build on piles.

The nature of the ground to be built upon should be ascertained by careful examination, and by boring or sinking test-holes. The former method is not to be relied upon, as it does not afford the means of judging whether the soil is very compact or otherwise. Trial pits should therefore always be sunk where great weights, as in the case of a high chimney shaft, have to be supported.

Rock affords an excellent foundation-bed, especially when it occurs

TABLE 95.

Description of Earth.	Approximate safe maximum load in tons per sq. foot.
Bog, morass, quicksand, peat moss, marsh land, silt	0 to 0·20
Slake and mud, hard peat turf	0 to 0·25
Soft, wet, pasty, or muddy clay and marsh clay..................	0·25 to 0·33
Alluvial deposits of moderate depths in river beds, etc..........	0·20 to 0·35
NOTE.—When the river bed is rocky and the deposit firm they may safely support 0·75 ton, but not more.	
Diluvial clay beds of rivers..	0·35 to 1·00
Alluvial earth, loams and loamy soils (clay and 40 to 70 per cent. of sand) and clay loams (clay and about 30 per cent. of sand)	0·75 to 1·50
Damp clay	1·50 to 2·00
Loose sand in shifting river bed, the safe load increasing with depth..	2·50 to 3·00
Upheaved and intermixed beds of different sound clays	3·00
Silted sand of uniform and firm character in a river bed secure from scour, and at depths below 25 feet	3·50 to 4·00
Solid clay mixed with very fine sand	4·00
NOTE.—Equal drainage and condition is especially necessary in the case of clays, as moisture may reduce them from their greatest to their least bearing capacity. When found equally and thoroughly mixed with sand and gravel, their supporting power is usually increased.	
Sound yellow clay containing only the normal quantity of water	4·00 to 6·00
Solid blue clay, marl and indurated marl, and firm boulder gravel and sand	5·00 to 8·00
Soft chalk, impure and argillaceous	1·00 to 1·50
Hard white chalk..	2·50 to 4·00
Ordinary superficial sand beds	2·50 to 4·00
Firm sands in estuaries, bays, etc....................................	4·50 to 5·00
NOTE.—The Dutch engineers consider the safe load upon clean firm sand as 5½ tons per square foot.	
Very firm, compact sand foundations at a considerable depth, not less than 20 feet, and compact sandy gravel	6·00 to 7·00
NOTE.—The sustaining power of sand increases as it approaches a homogeneous gravelly state.	
Firm shale, protected from the weather, and clean gravel ...	6·00 to 8·00
Compact gravel..	7·00 to 9·00
NOTE.—The relative bearing powers of gravel may be thus described :—1. Compact gravel. 2. Clean gravel. 3. Sandy gravel. 4. Clayey or loamy gravel. Sound, clean, homogeneous Thames gravel has been weighted with 14 tons per square foot at a depth of only 3 to 5 feet below the surface, and presented no indication of failure. This gravel was similar to that of a clean pebbly beach.	

in horizontal layers of coarse texture, and free from crevices or large flaws ; otherwise it is very treacherous and uncertain.

In order to prepare it for building on, all loose and unreliable portions should be cut away, and the hollows filled in with cement concrete; the rock may be cut into steps, which should be nearly horizontal, the outer edges having a slight inclination upwards. The lower joints of the structure resting on the steps should be set in cement, to prevent any tendency to unequal settlement.

Beds of rock lying in an inclined position, especially if there be thin layers of clay between them, are very liable to slide on each other when subjected to pressure. This may be guarded against in many places by cutting a trench across the slope of the beds of rock and filling it with concrete, so as to distribute the pressure arising from the tendency of the rock to slide downwards; the surface should also be covered with a good depth of concrete.

When it is found necessary to build upon a thin stratum of rock in preference to going through it, it will be better not to weaken it by cutting into it, but to build on its surface, giving a good spread to the footings.

Firm Earth.—The term "firm earth" includes hard dry clay, gravel, sand, etc. It is more than ever necessary to keep the intensity of pressure uniform in the case of foundations having to be made on hard dry clay, as it is liable to expand and contract under the varying influences of frost and wet.

A clayey soil, or even a shale rock, which is found very hard when being excavated, may become quite soft on exposure to the air; such ground should be covered in as soon as possible with a layer of concrete.

Gravel makes one of the best foundation-beds, as it affords good drainage and is unaffected by frost. It is often found in thin beds over a soft substratum; this can be discovered by trial pits.

A good bed for foundations is obtainable on sand if solid, uniform, and dry; if, however, it is affected by running water it might be washed away. Where sand has to be built upon, sheeting piles should be driven in all round the foundation to prevent its lateral escape. Piling may be considered as a convenient method for passing through a soft stratum to a hard one, so as to afford efficient support for heavy engineering works. Piling is also a powerful help in consolidating wet and soft soil to a considerable depth; the area thus consolidated should be enclosed in the first place with sheet piling, which thus affords a firm strata in opposition to the inferior one by being placed at right angles to it. The piling and the enclosed spaces together may be considered as a solid mass.

Depth.—Professor Rankine shows that, supposing the earth to have no cohesion, the weight of a building which is uniformly distributed over its base must not exceed the weight of the earth which it displaces in a greater proportion than $(1+\sin.\ \phi)^2$ to $(1-\sin.\ \phi)^2$; and further, that if the pressure of a building is not uniformly distributed over its base, as may sometimes be the case with chimneys subjected to wind pressure, the intensity of the pressure on the side where the pressure is greatest must not exceed $wx\left(\frac{1+\sin.\ \phi}{1-\sin.\ \phi}\right)^2$ and its least intensity must not fall short of wx, the intensity of the earth pressure at the same depth as that of the foundation. In this formula ϕ is the angle of repose of the soil, w its weight per cubic foot, and x the depth in feet below the surface.

The following Table, which has been compiled from Newman's "Earthwork Slips and Subsidences," gives the value of ϕ for various earths :—

TABLE 96.

Description of earth.	Angle of repose ϕ.	Weight per cubic foot.
	Degrees.	lbs.
Sand, very fine and dry	33 to 27	89 to 118
,, wet	26	
Soft chalk, impure and argillaceous	32 to 26	
Vegetable earth, dry	29 to 18	100 to 120
,, ,, loam	33 to 26	
,, ,, very wet	17 to 14	
Clay, dry	29	120 to 135
,, damp	18	
,, sound yellow, well drained	26 to 18	
,, wet	17 to 1	
Gravel, clean and compact	45	90 to 110
,, with sand	26 to 33	
Loose shingle	35 to 39	

The minimum depth for foundations on clay in this country is four feet, on account of the action of frost, and the maximum pressure on the foundation bed at this depth should not exceed two tons per square foot, but for every extra foot of depth this limit may be increased by one-fifth of a ton.

"The compressibility of oolitic and tertiary clays can only be overcome by piling, deep sinking, heavy ramming, or heavy weighting. The point of bearing must be carried below the possibility of upward reaction. The depth of a foundation in compressible ground ought not to be less than one-fourth the intended height of the building above ground—that is, for a shaft of 200 feet the foundations should be made secure to a depth of 50 feet by piling or by well sinking and concrete. Masses of concrete, brick or stone, placed on a compressible substratum, however cramped and bound, may prove unsafe. Solidity from a considerable depth can alone be relied upon. Mere enlargement of a base may not in itself be sufficient."

Footings.—To decrease the intensity of the pressure at the base of a building and ensure its stability, footings are formed. This is done by spreading the bottom out in regular offsets, which should never exceed two and a quarter inches (*i.e.*, a quarter-brick) on each side. The depth of the footings should be at least two-thirds the thickness of the wall to be supported, and the lowest course should never be less than six inches deep. In the case of heavy structures the footings should not spread more than their depth below the surface, and it is better, if possible, to keep it within one-half the depth.

If the footings are to rest on a bed of concrete care must be taken that the maximum pressure per square foot does not exceed the compressive strength of the concrete with a factor of safety of either four or eight, depending on its being subjected to a dead or live load.

The following Table gives the compressive strength of concrete in tons per square foot:—

TABLE 97.—COMPRESSIVE STRENGTH OF CONCRETE IN TONS PER SQUARE FOOT.

No.	Limes and Cements.	Weight per bushel.	Proportion of Lime or Cement to Gravel and Sand.			
			1 to 6.	1 to 8.	1 to 10.	1 to 12.
		lbs.	tons.	tons.	tons.	tons.
1	Grey Lime	—	10·2	4·6	5·2	—
2	" " Selenitic	—	18·5	7·6	8·1	—
3	Lias Lime	—	11·4	11·1	11·5	—
4	" " Selenitic	—	17·2	19·6	10·2	—
5	Lias Lime	—	23·0	10·7	8·5	—
6	Selenitic Lime	—	26·6	15·3	13·5	—
7	" Rugby Lias	—	37·1	34·2	21·1	—
8	" Aberthaw Lime	—	34·1	21·8	15·4	—
9	Rugby Lias Cement	74	17·2	10·7	5·8	—
10	Portland Cement	114	100·7	76·4	53·5	37·1
11	" "	120	86·4	91·7	52·2	29·1

Where a bed of concrete is laid under a building and allowed to project beyond these limits for the purpose of distributing and lessening the intensity of the pressure on the foundation-bed, it should be considered as a beam subjected to cross breaking stress, and its thickness calculated accordingly.

Table 98 on following page gives the results of experiments on the transverse strength of concrete, and is of great service in making such calculations.

Wind Pressure.*—It has been found by experiment that when a thin plate as in the case of an anemometer is exposed normally to the wind, there is in addition to the direct front pressure a negative back pressure; it is the sum of these two pressures that an anemometer

* *Vide* Lecture by Professor W. C. Unwin, F.R.S., M.I.C.E., at Chatham, in 1897.

registers. In many cases, however, the convergence of the wind at the back of a structure is interfered with or prevented. The wall of a building, for instance, carries the front pressure only, and in such cases the pressure due to any wind velocity is only 0·6 of the anemometer pressure.

TABLE 98.—TRANSVERSE STRENGTH OF CONCRETE SUPPORTED AT ENDS.

Proportions of ingredients.			Modulus of Rupture (r) in cwts. per square inch.
Portland Cement.	Sand.	Aggregate.	
1	—	1 Coke breeze	5·99
1	—	2 Crushed brick	1·74
1	2	" "	3·88
1	—	4 Clean breeze	4·15
1	—	4 Broken brick	3·11
1	0	5 Shingle	2·73
1	1	5 "	2·21
1	2	5 "	1·42
1	3	5 "	0·89
1	2	6 Gravel	1·39
1	2 —	2 Broken stone 7½ ins. 4 " " 3½ ins.	1·56
1	2	6 " " 1½ ins.	1·22
1	0	9 Shingle	1·27
1	1	8 "	1·18
1	2	7 "	0·94
1	3	6 "	0·58
1	3	6 " (screened)	0·92
1	4	5 " "	0·59
1	1	½ Gravel ¾ inch 3 Broken stone 1 in. to 4 in.	4·17

The following Table gives the results of the experiments of Mr. Smeaton and Mr. Dines with plates struck normally, involving both direct front pressure and negative back pressure.

TABLE 99.

V, Miles per hour.	P, lbs. per square foot.	
	Smeaton.	Dines.
25	3·1	2·2
50	12·5	8·8
75	28·1	19·7
100	50·0	35·0
150	112·5	78·8

The relation between wind velocity and pressure on a thin plate is given by the following formula :—

$$P = 0{\cdot}005\ V^2$$

where P is the pressure in lbs. per square foot, and V is the velocity in miles per hour.

Numerous experiments show that the wind velocity, and consequently the wind pressure, increase with the height above the ground. The results obtained by Mr. Stevenson in 1878 with strong winds blowing over a level field are that for a height of 15 feet from the ground the velocities were low and irregular even when the wind was strongest. For heights above 20 feet, the ordinates of the velocities at different levels in every case were those of a parabola having its vertex 72 feet below the ground level, so that

If V and v are velocities at heights H and h above the ground level,

$$V = v\sqrt{\frac{H+72}{h+72}}$$

Hence, if P and p are the pressures at these heights,

$$P = p\sqrt{\frac{H+72}{h+72}}$$

Supposing the pressure at 50 feet is 30 lbs. per square foot, then by Mr. Stevenson's law, assuming that it may be extended to great heights, we get :—

TABLE 100.

Height above ground in feet.	Wind pressure in lbs. per square foot.
50	30
100	42
200	66
300	91

We thus see the importance of attending to wind pressure in lofty structures.

Pressure on Solid Bodies of Various Forms.—When a solid body is presented to the wind the front pressure is modified if the face of the body is not plane, and the negative or back pressure is modified if the form of the body interferes with the convergence of the air in the wake. If we put K for the ratio of the pressure on a body to the pressure on a thin plate, of area equal to its projected area on a plane normal to the wind, then we have the values of K in Table 101.

TABLE 101.

Shape of object.	K =	Wind.
For a sphere	0·31	
„ cube	0·81	Normal to face.
„ „	0·66	Parallel to diagonal of face.
„ cylinder (height = diam.)	0·47	Normal to axis.
„ cone (height = diam. of base)	0·38	Parallel to base.

On a cylindrical chimney, for instance, the wind pressure would be only about one-half that on a thin plate of area equal to the projected area of the chimney.

The effect of obliquity of surface to the direction of the wind is expressed by the empirical formula of Duchemin (*vide* article on Hydraulics in the "Encyclopædia Britannica," p. 518, by Professor W. C. Unwin, F.R.S., M.I.C.E.)—

If ϕ is the acute angle between the plane and the wind's direction, and P the pressure per square foot of a plane due to the same wind striking the plane normally ($\phi = 90°$), then for any other inclination the normal pressure per square foot is

$$N = P \frac{2 \sin. \phi}{1 + \sin.^2 \phi}$$

When a plane is oblique to the direction of the wind the pressure is greater toward the leading edge; this appears to apply to both the positive and negative pressures. Thus in the case of a rectangular surface at an angle ϕ to the direction of the wind, the centre of pressure may be considered as situated at unequal distances, a and b, from the leading and following edges of the plane. Thus we have the following value for $\frac{a}{b}$:—

TABLE 102.

ϕ.	$\frac{a}{b}$.
72°—75°	0·9
57°—60°	0.8
43°—48°	0·7
25°—29°	0·6
13°	0·5

If the oblique plane is not freely exposed, but the direction of the current of air is diverted by other planes in its vicinity, as in the case of a roof resting on a wall, then the effect of the wall is to throw up a current of air which more or less diverts the pressure from the roof; the higher the wall in proportion to the length of roof the greater is the sheltering effect produced.

TABLE 103.

Inclination of roof to horizontal.	Normal pressure on oblique plane height (l).		
	Freely exposed.	Sheltered by wall of height = $1\frac{1}{4}$ l.	Sheltered by wall of height 0·5 l.
60°	95	55	75
45°	87	25	55
30°	72	10	14
20°	54	0	0

The pressure on a vertical surface equal to the roof area being 100.

The results given in Table 103, on preceding page, were obtained by experiments made by Professor Kernot.

As regards wind pressure on bridges, the Board of Trade Committee of 1881 recommended that a factor of safety of 4 should be adopted in fixing the limiting stresses; and as regards mere overturning of the bridge by wind pressure, they considered a factor of safety of 2 sufficient.

Chimney Shaft—Stability of.—It is usual to design a chimney shaft in the first place, and then calculate its stability, which should be independent of the strength of the mortar with which it is constructed. The only external force to be dealt with is the wind-pressure, and this is generally taken at 50 lbs. to the foot super, which should be ample for the British Isles; but in the case of very lofty chimneys in exposed situations the increase of pressure with height above the ground level, as pointed out by Professor Unwin at p. 597, *ante*, should certainly be kept in view. It is very probable that the excessive rocking of some tall chimneys is due to this point having been overlooked in their design.

The first step is to ascertain the weight of the shaft on the joint of maximum compression, which is situated where the wind-pressure reduces that of the superincumbent masonry to *nil* at the windward edge, and is found generally either at the ground-level or on the top of the pedestal, if there is one.

The moment of Inertia of the joint at this level is required, and for a circular shaft $=\frac{\pi}{4}(r^4-r_1^4)$, where r and r_1 are the radii of the outer and inner faces of the shaft.

Thus if p = the actual force of the wind in lbs. per square foot,
S = area of diametral plane,
h = height of chimney above the joint in feet,

the moment of wind-pressure for a *circular* chimney $=M=S\times\frac{p}{2}\times\frac{h}{2}\times\frac{1}{2240}$ foot-tons.

Here the centre of pressure is taken at one-half the height of the chimney, which is above the centre of gravity of the diametral plane; but according to Stevenson's law the centre of pressure, especially in exposed positions, would be found at some distance still higher above the ground level.

The area of the cross section of the joint under consideration is $A=\pi(r^2-r_1^2)$ for a circular joint, and $A=D^2-d^2$ for a rectangular cross section.

By substituting the appropriate values thus obtained in the following equation, and making $y=o$, we get the value of p.

$$y=\frac{N}{A}-\frac{M\times t}{2I}=o$$

where

y = minimum compression per unit of area.
N = total normal pressure on the joint.
A = the area of the cross section of joint.
t = the maximum width of the joint.
I = the moment of Inertia of the cross section.

The maximum pressure at this joint $=2\frac{N}{A}$, and must not exceed in intensity the safe working stress of the materials.

If the joint thus tested is on top of a pedestal, the calculations should be repeated, after making the necessary changes, at the ground level; the stability at each decrease of thickness of brickwork in the shaft should then be tested in the same way.

To ascertain the maximum pressure on the foundations, we must find the position of the centre of pressure at the base of the shaft.

According to Rankine, the approximate positions for centres of pressure, under the condition *that the pressure decreases uniformly from a maximum at one edge to nothing at the opposite edge*, are situated, for a hollow square factory chimney, at a distance of $\frac{1}{6}t$ to $\frac{1}{3}t$ from the edge of maximum compression, and in the case of a circular ring $\frac{1}{4}t$; these positions are, however, only correct for thin rings. A more accurate determination is afforded by Captain C. F. Close, R.E., *vide* p. 326, "The Principles of Structural Design," by Major Scott-Moncrieff, R.E., where if q = the distance of centre of pressure from the windward edge, then for a circular cross section where D and d are the outer and inner diameters, we have

$$q=\frac{5D^2+d^2}{8D}.$$

Similarly for a square section, where D and d are the lengths of the outer and inner sides,

$$q=\frac{4D^2+d^2}{6D}.$$

If now we compound the total weight of the shaft, acting through the centre of pressure thus found, first with the weight of the footings and then these two together with that of the concrete base, we obtain the position of the centre of pressure on the foundation-bed.

The above operation may be effected either graphically, or by taking moments about the outer edge of the shaft or foundation-bed respectively.

The following formula gives the maximum pressure on the foundation-bed (*vide* p. 355, "Instruction in Construction," by Colonel Henry Wray, R.E., now Major-General Wray, C.M.G., R.E.) :—

$$Y = \frac{2N}{t}\left(2 - \frac{3d}{t}\right)$$

where

N = total normal pressure on the bed.

t = length of the concrete bed in the direction of maximum pressure.

d = minimum distance of the centre of pressure as previously found from the outer edge of the joint.

The value of Y thus found should be within the bearing capacity of the soil; *vide* Table 95, page 592.

As regards the cross breaking strength of the concrete bed it is best to consider the offsets of the footings as elastic, for it is not to be supposed that the extremity of the footings can bear as much as the portion close to the outer edge of the superincumbent masonry; if then we take it as *nil* at the point and increasing to the mean normal pressure at the thickest point, the centre of pressure for the offset will be at a distance outwards of one-half its breadth. The moment of flexure should therefore be taken about this point, the upward pressure being the mean pressure on the projection beyond the centre of the footings multiplied by the distance of its centre of pressure from the centre of the footings.

Example.—To inquire into the stability of the chimney in Plate LXa, page 572. Taking the brickwork at 112 lbs. to the foot cube, we get from the top downwards :—

	Tons.
Weight, 1st section	58·65
„ 2nd „	67·15
„ 3rd „	75·47
„ 4th „	113·98
Weight of shaft	315·25
Pedestal	232·21
Carried forward	547·46

	Tons.	Tons.
Brought forward		547·46
Firebrick lining at 150 lbs. to ft. cu.	17·37	
Footings	110·90	
		128·27
		675·73
Concrete base at 131 lbs. to ft. cu.		526·33
Earth supported		170·46
Total weight on foundation-bed		1372·52

If S = area of diametral plane of chimney above joint to be examined, in this case the foot of the pedestal:

N = 547·46 tons.

$S = 1484{\cdot}6 + 24 \times 14'\,6'' = 1484{\cdot}6 + 348 = 1832{\cdot}6$ square feet.

$M = S \times \frac{p}{2} \times \frac{h}{2}$ foot lbs. $= 32{\cdot}7 \times p$ (foot-tons).

Assuming the pedestal to be square inside as well as outside :

$A = 14'\ 6''^2 - 8'\ 6''^2 = 138$ square feet.

$t = 14{\cdot}5$ feet.

$$I = \frac{1}{12}(D^4 - d^4) = \frac{1}{12}(14'\ 6''^4 - 8'\ 6''^4) = 3248{\cdot}75 \text{ (feet)},$$

then

$$y = \frac{N}{A} - \frac{Mt}{2I} = \frac{547{\cdot}46}{138} - \frac{32{\cdot}7 \times p \times 14{\cdot}5}{2 \times 3248{\cdot}75} = 0.$$

As there is now no tension on windward side,

$$\therefore p = 54{\cdot}36 \text{ lbs. per square foot,}$$

which is ample.

Maximum pressure on this joint $= 2\frac{N}{A} = 7{\cdot}934$ tons per square foot,

$= 123{\cdot}4$ lbs. per square inch,

which is well within the crushing strength of good stock brickwork in lias lime mortar, taken at 400 lbs. per square inch.

Similar calculations might be made at each joint where an alteration in thickness of masonry occurs.

Foundations.—To ascertain position of centre of pressure :—

$q = \frac{4D^2 - d^2}{6D} = \frac{4 \times 14{\cdot}5^2 - 8{\cdot}5^2}{6 \times 14{\cdot}5} = 8{\cdot}83$ feet, and is thus situated at a point $1{\cdot}58$ feet from centre line. Compounding the weight through this point with that of the footings, we get by taking moments :

$$q_1 \times 675{\cdot}73 = 547{\cdot}46 \times 8{\cdot}83 + 128{\cdot}27 \times 7{\cdot}25$$

$$\therefore q_1 = \frac{4834{\cdot}1 + 929{\cdot}96}{675{\cdot}73} = 8{\cdot}5286$$

or $1{\cdot}2786$ feet from the centre line.

Compounding these two weights with the concrete bed, earth-filling, and brick-lining :

$$q_2 \times 1372{\cdot}52 = 675{\cdot}73 \times 16{\cdot}2786 + 696{\cdot}79 \times 15$$

$$\therefore q_2 = \frac{11000 + 10452}{1372{\cdot}52} = 15{\cdot}63 \text{ feet}$$

and minimum distance from outer edge $= 30 - 15{\cdot}63 = 14{\cdot}37$ feet.

The maximum pressure is obtained as follows :—

$$Y = 2\frac{N}{t}\left(2 - \frac{3d}{t}\right) = \frac{2 \times 1372{\cdot}52}{30}\left(2 - \frac{3 \times 14{\cdot}37}{30}\right)$$

$= 51{\cdot}5$ tons on outer edge.

$$\therefore \text{Pressure per square foot} = \frac{51{\cdot}5}{30} = 3{\cdot}4 \text{ tons.}$$

This is perfectly safe, as the bearing strength of gravel is from 6 to 8 tons per square foot (Table 95, page 592).

To ascertain whether the thickness of the concrete bed is sufficient, it is necessary to find centre of pressure on projecting portion from centre of footings :—

Half-width of footings $=\frac{23' \, 2'' - 15'}{4} = 2' \cdot 1''$

Length of projection $= 15 - (7' \, 6'' + 2' \, 1'') = 5' \, 5''$

Pressure at centre of footings in excess of normal pressure $= \frac{9' \, 7''}{15} \times \frac{\cdot 1847}{2} = \cdot 05902$ cwts.

Total pressure at this point $= \frac{\cdot 1847}{2} + \cdot 05902 = \cdot 15132$

Distance of centre of pressure of projection from centre of footings $= \frac{\cdot 1847}{\cdot 15132 + \cdot 1847} \times 5' \, 5'' = 35 \cdot 71$ ins.

and $M = (\cdot 1513 \times \cdot 1847) \times 35 \cdot 71 \times 5' \, 5''$

$\therefore \frac{rbd^2}{6} = 4 \times \cdot 336 \times 35 \cdot 71 \times 65$

$\therefore d^2 = \frac{24 \times \cdot 336 \times 35 \cdot 71 \times 65}{1 \cdot 39}$ (as $b=1$)

[$r = 1 \cdot 39$ for concrete, 1 Portland cement, 2 sand, 6 gravel, *vide* Table 98, p. 596.]

$\therefore d = 115 \cdot 9$ inches $= 9 \cdot 6$ feet.

The depth of the foundations in this case is one-tenth the height of the shaft.

Cardiff Report on Methods of Disposal of House Refuse.—The following summary of the Cardiff Report is taken from *The Surveyor* of January 5th, 1897 :—

"A special committee appointed by Cardiff Corporation has just reported upon visits which it paid to a number of important towns to inspect the methods there adopted for disposing of house refuse. The deputation during its investigations was struck with the fact that in nearly every place it visited the official in charge of the works considered his method and his type of destructor the best and unsurpassable. There were, however, two exceptions to the general rule. The city engineer of Liverpool does not recommend the conveyance of the refuse to sea in steam hoppers, and the Liverpool Corporation was contemplating erecting more destructors and discontinuing the steam hoppers, while at Glasgow the conveyance of the refuse of 750,000 persons into the country by rail daily is found to be no small undertaking, and the advice given there was to burn as much as possible, so as to reduce the bulk to a minimum. As to type of destructor, the deputation believes, from what it saw, that high temperature furnaces are the best, requiring, ton for ton, no greater manual labour, and requiring fewer furnaces and less space upon which to erect them. One of the great drawbacks which the deputation finds to a destructor system is the large percentage of ashes and clinker to be disposed of subsequent to the burning, generally from 30 to 40 per cent., and in nearly every town visited the getting rid of this large residue from the burning is no trifling matter, but in some cases amounts to a real difficulty, involving considerable cost. A minute stands on the books of the Cardiff Corporation prohibiting in future any street being formed 'with ashes, town refuse, or other deleterious matter,' because corrosion of water mains and service pipes resulted from chemicals known to exist in ashes and refuse; and the deputation says, if this resolution is to stand, the chief source of output for the clinker and ash refuse from destructors is gone, and its ultimate disposal must become a costly matter. It, however, points out that other towns 'take the precaution of surrounding the pipes with a protecting substance,' where gas or water pipes are laid in such materials. Two visits paid to Chelsea convinced the deputation that there is a possibility of utilising the bulk of the refuse to better advantage than by burning the whole of it; and having obtained all the information which can well be gathered, it recommends a combination, with modifications and additions, of the systems which they have seen elsewhere. This would consist of: (1) The machinery for separating the refuse such as employed by the Chelsea Refuse Disposal Company, but omitting the grinding up and washing of the vegetable matter, and also the washing of the fine dust into the sewers, which should, in the opinion of the deputation, be separated in a dry state and burnt. (2) The conversion of waste paper, rags, &c., into brown paper and mill-boards on the premises. (3) The grinding or crushing of raw bones on the premises. (4) The erection of a clinker mill for breaking up clinkers, etc., for fine concrete making. (5) The washing of the rough screening for producing fuel for boiler purposes. (6) The erection of a furnace for extracting the tin and solder off old tin cans, and converting the tin plates into a more saleable article. (7) The erection of one or more mortar mills for making mortar for use on corporation works and for sale. (8) The provision of a steam disinfector for disinfecting bedding and clothing from infected houses in the borough. (9) The erection of a refuse destructor of the Beaman and Deas type for consuming the dust, animal and vegetable matter, diseased meat, infected bedding and clothing, etc. The deputation believes that by the establishment of a depôt and works such as it has described the bulk of the refuse might be sold, and that the money to be realised therefrom would more than cover the cost of disposing of the refuse, while by adopting the steam hopper or destructor system only there appears to be small hope of obtaining any considerable return. The deputation suggests the establishment of works in Cardiff."

GRAPHICAL DETERMINATION OF THE VALUE *C*, GANGUILLET AND KUTTER'S FORMULA.

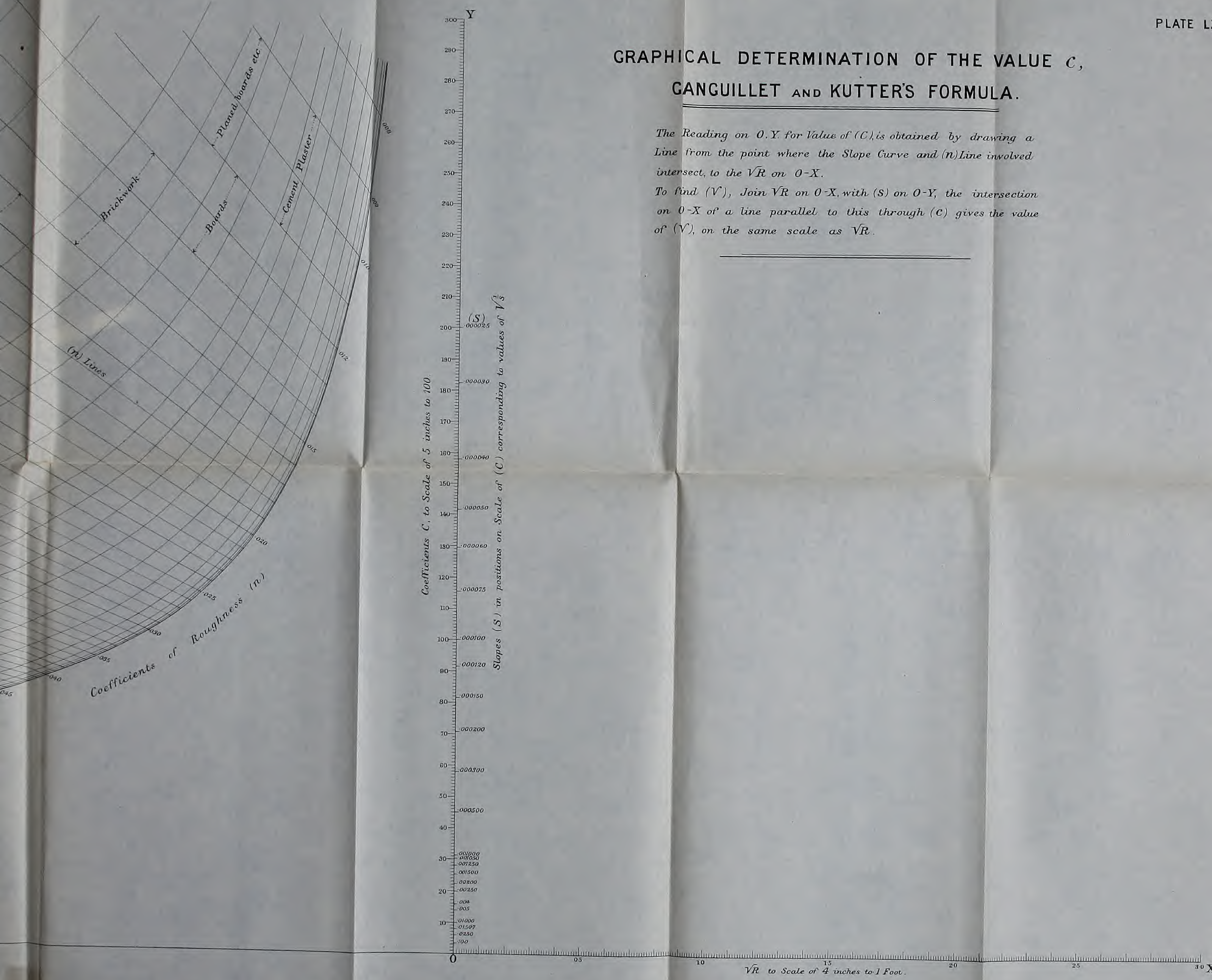
The Reading on O.Y for Value of (C), is obtained by drawing a Line from the point where the Slope Curve and (n) Line involved intersect, to the √R on O-X.

To find (V), Join √R on O-X, with (S) on O-Y, the intersection on O-X of a line parallel to this through (C) gives the value of (V), on the same scale as √R.

GRAPHICAL DETERMINATION OF THE VALUE C, GANGUILLET AND KUTTER'S FORMULA.

The Reading on O.Y. for Value of (C), is obtained by drawing a Line from the point where the Slope Curve and (n) Line involved intersect, to the $\sqrt{R}$ on O-X.

To find (V), Join $\sqrt{R}$ on O-X, with (S) on O-Y, the intersection on O-X of a line parallel to this through (C) gives the value of (V), on the same scale as $\sqrt{R}$.



INDEX.

A.

A B C process of sewage purification, 455
Abrading and transporting power of water, 77
Absolutely separate system, 3, 11
Access pipe to sewer, 208
Adams' patent automatic sewage lift, 24
Admission of rain water to drains, 80, 286
Advances in sanitary science, 2
Aëration and bacterial oxidation, purification of sewage by, 514
—— of land used for sewage filtration, 438
Aërial deodorants, 420
Afflux or height to which river is raised by obstruction, 69
Air compressors, 20
Air inlet for house drains Elliott's patent, 268
—— in footpath, 267
—— in kerb, 267
—— inlet to soil pipes, 279
—— to soil pipes, 279
—— Beaumont's patent valve, 280
—— Cregeen's patent, 279
—— Simmance's patent, 280
Air-tight covers, 239
—— the "Loco," 240
—— Hellyer's, 241
Alumino-ferric (Spence's) for sewage disposal, 450
Amines process for sewage disposal, 445
Amount of sewage, estimate of, 29, 30
Analysis of house refuse, 541
Animal refuse injurious to health, 1
Angular section, channel, example of application of formulæ for velocity and discharge, 180
Antiseptics, 419
Apparatus, sanitary, 309–374
Area of cross-section of sewer, 29
Artificial stone made from "destructor" clinkers, 550
Aylesbury, disposal of sewage at, 455

B.

Bacterial oxidation and forced aëration, purification of sewage by, 514
Bacteria and algæ, growth of, 467
Bacteria tanks at Sutton, 496A
Bacteriolysis system of sewage disposal, 427, 474–528
Ball tide valve, 305
Barking, Metropolitan Sewage Works, 428, 445, 446, 511
Basins, lavatory, 359
—— the "Loco," 361
—— the "Tip-up," 361
Baths, copper, zinc, iron, slate, porcelain, 357
—— waste from, 358
Battersea, destruction of town refuse, 550
Beaman and Deas' patent destructor, 555
Beddington, irrigation farm at, 435
Bends, angular, effect of, on pipes and rivers, 62
—— circular, loss of head due to, 62
Bennett-Phythian destructor, 553
Bernouilli, Daniel, on flow of liquid in channels, 39
Binnie, Sir A. R., Experiments on sewage disposal, 493
Biological treatment of sewage, 427, 474–528
Birmingham, disposal of sewage at, 445
—— of sludge at, 535
Blue lias lime, 201
Boggy land, drainage of, 402
Boilers for refuse destructors, 568, 558, 563
Boning rods for laying drains, 219
Boracic acid, 420
Borax, 420
Boro-phenol, disinfecting powder, 420
Bottom velocities (Bazin), 74
Boulnois' charging tanks for destructors, 551, 584
Bower-Barff process for coating pipes, 243
Bradford, disposal of sewage at, 454
Brahms, on flow of liquid in channels, 39
Breakage of stoneware pipes, causes of, 225
Bricks for sewers, 203, 228
—— amount required, 229
—— testing, 229
Brickwork for sewers, thickness of, 229
Bristol, sewerage and sewage disposal works at Mangotsfield, 456–462
Broad irrigation, distribution over land, 434

Broad irrigation, distribution over land, Beddington, 435
—— preparation of land, 435
Bromine, 419
Brushwood for subsoil drainage, 402
Buddle-hole, 383
Burnley, disposal of sewage at, 445

C.

Calvert's carbolated creosote, 422
Camphorine liquid for disinfecting, 420
Capacity of land to purify sewage, 437
Carbolic oil and acid, 420, 421
Cardiff report on destructors, 603
Castelli on flow of liquid in channels, 38
Cast-iron drain pipes, 241
—— advantages of, 244
—— the Bower-Barff process, 243
—— Dr. Angus Smith's process for, 243
—— glass-enamelled, 248
—— joints for, 248
—— flexible joint, 248
—— dimensions of socket connections, 247
—— turned and bored sockets, 248
—— approximate weight of socket pipes, 246
—— rust joint, 253
—— method of caulking, 253
Cast-iron pipes for syphons, 254
—— for outfalls, 254
Catchpits for surface water, 378
Catchwater system of sewage disposal, 435
Caustic lime, 403
Cement, Portland, 199
—— house for, 201
—— mortar, 201
Centering for egg-shaped sewers, 232A
Cesspits, 4
Channel gully, self-cleansing, Ducketts', 284
—— Mooney, 285
Channels, open, flow of liquid in, 37
—— of introduction of zymotic disease, 1
Chart of sewer ventilation, 288B
Chemical treatment of sewage, precipitation, 441
Chezy, on flow of liquid in channels, 40
Chichester barracks, disposal of sewage at, 464
Chimney shafts for destructors, 588–603
—— average height of, 590
—— cost of, 590
—— depth, 593
—— dimensions of, 588
—— firm earth, 593
—— footings, 595
—— foundations, 590
—— object of, 588
—— pressure on solid bodies, 597
—— stability of, 599
Chimney shafts for destructors, wind pressure on, 595
Chloride of lime, 422, 419, 420
Chlorine, 419
Chokage of drain pipes, causes of, 226
Circular sewers, pipes, and conduits, velocity and discharge of, 128–159
Cisterns, for urinals, automatic flushing apparatus for, 349
—— Crapper's automatic, 350
—— Twyford's syphon, 350
—— Merrill's flushing syphon and tanks, 350
Cisterns, waste-preventing, with valves and with syphons, 330
—— Crapper & Co.'s, 331
—— Doulton's vacuum water waste preventer, 331
—— Ducketts' A 1 stoneware, 331
—— Shanks' reliable improved, 331
—— "Stafford" syphon, 331
—— syphon plunger, 332
—— Twyford's national, 331
—— Westminster, 331
—— "Winn's Acme," 330
Clay soils, drainage of, 392
Clay, use of, as a jointing material, 209
Clean water - closets, 313. And *see* Water-Closets
Clinkers from destructors, utilization of, 545, 549–551, 575
Closets. *See* Water-Closets
Coast line, configuration of, 428
Collection and removal of sewage, 3–10
—— of house refuse, 529
Collection of surface water, 375–384
—— combined system, 379
—— separate system, 378
—— admission to foul drain, 384
—— buddle-hole, 383
—— catchpits for, 378
—— connection with foul water drain objectionable, 375
—— down pipes, joints in, 375
—— drains for, 378
—— eaves, gutters for, 375
—— gully for, Crosta's, 381
—— —— Ducketts', 383
—— —— Lovegrove's, 383
—— —— Newton's street, 380
—— —— Sykes', street and yard, 383
—— —— Stokes', 383
—— —— Turner and Croker's, 380
—— stench trap for, Cartwright's, 382
—— surface channels for, 375
—— traps for, Dean's, 382
—— —— Duplex cesspool, Hagen's, 382
—— —— Lowe's, 380
—— —— Mason's or dip traps, 379
Combined drains, 14
Combined sewage and rainfall, estimate of, 32
Comparison of systems of collection and removal of sewage, 9

Combustion. *See* Destructors
—— forced draughts for, 566
—— power required to drive fans for, 567
Compressed air, Shone's hydro-pneumatic system, 17–23, 571, 580
—— Johnson's and Hutchinson's hydro-pneumatic system, 532
Concrete, 202
—— strength of, 594
—— use of clinkers for making, 549, 551, 575
Concrete sewers, thickness of, 233
Conder's sulphate of iron process for sewage disposal, 463
Condy's fluid, 422
Connection of house drains with sewers, 27
Connection with soil pipe for water-closets, 318
Connections between pipes of different materials, 255
—— of iron soil pipe with iron bend, 253
—— of lead soil pipe with iron bend, 253
Conservancy system, 8
Constructing drains, &c., preliminary arrangements, 218
—— use of "sight-rails," &c., 219
—— excavating trenches, 220
—— methods of timbering, 220
—— tunnelling, 223
Construction of, and materials for sewers and drains, 199–260 *See also* Sewers
Conveniences, public (underground), 286, 342
—— ventilation of, 287
Corfield, Prof., on sewage purification, 489
Cost of construction of destructors, 541
Cost of destruction, 541
Cost of removal of excrement, dry earth system, 8
Coulomb on flow of liquid in channels, 41
Coventry, disposal of sludge at, 537
Covers, air-tight manhole, 239–241
Cowls, Banner, Boyle, Buchan, Hellyer, Kite, Sugg, Weaver, 280
Cregeen's patent air-inlet, 279
Cremator, Jones's fume, 547, 557
Cressol, 421.
Cresylic acid, liquid for disinfecting, 420
Crimp's, Mr. Santo, experiments on sewer ventilation, 273
Crops suitable for irrigation, 437
Crossness, Metropolitan Sewage Works, 428, 445, 446, 469, 470, 473
Cross sections of sewers, 28. *See also* Sewers
Croydon, Beddington irrigation farm at, 435
Cultivation filter bed, Scott-Moncrieff's system, 481
Culverts, iron pipes for ramp, 15
Culverts, old, to be destroyed, 418
Curing damp walls, Colonel Moore's process for, 404
—— advantages of, 405
—— general remarks on, 405

D.

Dale's muriate of iron process for disposal of sewage, 465
Damp walls, Colonel Moore's process for curing, 404
—— advantages of, 405
—— general remarks on, 405
Darcy and Bazin's formula, 43
Decomposing sewage, danger of, 261
Definition of sewage, 2
Deflecting "Loco" trap, 298
Deflection, draining by, 27
Deodorizer, but not an antiseptic, 420
Deposits in sewers, velocity required to prevent (Baldwin Latham), 79
De Prony on flow of liquid in channels, 41
Destruction, disposal of sludge by, 535
—— disposal of house and town refuse by. *See* Destructors
—— of sewer-gas, 273–275
Destructive velocities (Flynn), 76
Destructors, refuse, general remarks on, 540
—— analysis of refuse, 541
—— Beaman and Deas, 555
—— Bennett-Phythian, 553
—— boilers for, 558, 563, 568
—— Cardiff report on, 603
—— charging, method of, 563, 584
—— charging tanks for, 551, 584
—— chimneys for, 573, 588–603
—— classes of, two, 545
—— clinkers from, 545, 549, 550, 551, 575
—— cost of working, 541, 548
—— cost of construction, 541
—— cremator for use with, 547, 557
—— design of, 540
—— forced draught for, 566, 551, 557
—— Fryers', 546
—— high temperature, 540, 545
—— Horsfall's, 551
—— Jones's improved pattern at Ealing, 546
—— in operation at Battersea, 550; Ealing, 546; Leyton, 555; Rochdale, 558; Hereford, 559; Shoreditch, 583; Oldham, 553; Salford, 558; Southampton, 573; Liverpool, 550, 603; Glasgow, 603; Chelsea, 603
—— Manlove, Alliott's, 550
—— Meldrum's, 557
—— production of electric light from, 575, 583
—— production of power from, 544, 575
—— slow combustion, 545
—— thermal storage, 583

Destructors, types of, 545
—— utilisation of waste heat from, 542, 575
—— Warner's "Perfectus," 553
Dibdin and Garfield filters, comparison of results, 506
Dibdin, experiments of, on biological lines, 494
Discharge of circular sewer pipes and conduits calculated by Kutter's formula, 128–159
—— of egg-shaped sewers, calculated by Kutter's formula, 160–173
—— of water over a notch or weir, formula for, 67
—— of syphons, 65
—— of sewage into sea, 427
—— tidal estuary, 427
—— land-locked harbour, 428
Discharges of pipes, table of, 34
Disconnecting cast-iron trap, 298
—— pits, 277
—— slipper, Sykes' patent, 285
Disinfectants, powerful or germicide, 419
—— weak, 419
—— use of, 420
—— method of application of, 422, 423
Disinfecting, powders for, 420
—— liquids for, 420
Disinfecting apparatus for water-closets, 323
Disposal of sewage, processes for. *See also* Sewage Disposal
—— the A B C, 455
—— the Amines, 445
—— Conder's sulphate of iron, 463
—— Dale's muriate of iron, 465
—— dry earth, 427
—— the Hermite, 465
—— the International, 456
—— Richmond Main Sewerage Board Works, 450
—— lime, 445
—— lime and alumina, 446
—— lime and sulphate of iron, 445
—— the Natural Purification Company's system, 451
—— oxygen process, 496D–505
—— the Scott-Moncrieff system, 526
—— septic tank system, 509
—— Spence's alumino-ferric, 450
—— Sutton bacteria tanks, 496
—— the "Universal" Sewage Purification Co. (the "Ives" patent), 453
—— variety of processes, 444
Disposal of house refuse and sludge, 529–604
—— at Wimbledon, 537; Salford, 535; Manchester, 535; Liverpool, 532, 603; Southampton, 570; Ealing, 546; Leyton, 555; Birmingham, 535; Rochdale, 536; Coventry, 537
Dortmund settling tank, 434
Double ventilation, 15
Drain pipes, cast-iron, advantages of, 244
—— approximate weight of, 246
—— Dr. Angus-Smith's process for, 243
—— the Bower-Barff process, 243
—— dimensions of socket connections, 247
—— flexible joint, 248
—— glass enamelled, 248
—— joints, turned and bored sockets, 248
—— method of caulking, 253
—— rust joint, 253
Drain plugs, 412
Drain testing, 409–417
Drain-testing apparatus,
—— drain grenades, 416
—— Burnet's smoke drain tester, 417
—— the Champion fumigator, 416
—— the Eclipse smoke generator, 415
—— Kemp's drain tester, 417
—— Pain's smoke generator, 417
—— the Tyndale generator, 416
—— the Watts asphyxiator, 416
Drains of blocks of enclosed buildings, ventilation of, 286
—— combined, 14
—— necessary even where interception is employed, 9
—— surface water, 378
—— size and inclination of main house, 36
Drains and sewers, definition of, 13
—— extra fall at junctions and curves, 15
Drains under buildings, 255, 392
—— ventilation of, 286
—— "flushing," syphons for, 366
Drains, trenches for, 220
—— construction of, 218
—— laying, preliminary arrangements, 218
Drainage, general principles, 14
—— systems of single, 276
—— combined, 276
—— house, 278
—— air drains, 376
—— arrangement of drains, 388
—— clay soil, 392
—— damp walls, Colonel Moore's process for curing, 404
—— —— advantages of, 405
—— —— general remarks on, 405
—— deflection, Lynde's principle, 27
Drainage, subsoil, General Report of the Commission on improving the sanitary condition of barracks and hospitals, 385
Drainage, subsoil, 385–406
—— bottom to be currented accurately, 395
—— brushwood, 402
—— depth of drains, 387
—— distance between drains, 389
—— direction of drains, 389
—— execution of, 394

Drainage, subsoil—*continued*
—— failure of drains, 402
—— fall for drains, 388
—— filling in trench, 399
—— fine earth, and its object, 400
—— flushing drains, 392
—— hand-packing, 401
—— of boggy land, 402
—— of laundries, 260
—— of stables, 256–260
—— outlets to drains, 390
—— peaty soil, 394
—— pipe-laying, and method of, 399
—— pipes for, material and size, 395
—— —— junctions of, 398
—— —— quality of, 397
—— plan of, necessary, 403
—— roads, 403
—— roots of trees, 403
—— silt, 402
—— silt basin, 390
—— special for footings, 393
—— special measures for underground buildings, 403
—— stones over pipes, 400
—— sumps, use of, 391
—— surrounding site of buildings, 392
—— trenches, depth of, 394
—— under foundations, 255, 392
—— under buildings, 392
—— under railway embankments, 394
—— vermin, 403
Drying earth, arrangement for, 8
Dubuat on flow of liquid in channels, 40
Ducketts' automatic tippers for flushing, 372
—— self-cleansing channel gully, 284
Dundrum settling tank, 434
Dust carts, 534, 547, 574

E.

Ealing Sewage Works, refuse destructors at, 546
Earth closets, 6
Edinburgh, sewer ventilation at, 288D
Effluents, relation of, from chemical precipitation to the growth of bacteria and algæ (Massachusetts experiments), 467
Effluents, trade, 502
Egg-shaped sewers, 66, 67, 229
—— adequate foundation for, 233
—— centering for, 232A
—— concrete, 233
—— dimensions and brickwork required, 231
—— invert blocks, 232B
—— some methods of construction, 232
—— old form, 66
—— new form, 66
—— Jackson's peg-top section, 67
—— velocity and discharge of, 160–173
Ejector, Shone hydro-pneumatic, 17–23, 571, 580
Elbow in stream, loss of velocity due to, 62
Electric filter for sewage, 471
Electric light, production of, from waste heat of destructors, 575, 583
Electrolysis, precipitation by, 469
—— Sir H. Roscoe's report on, 472
—— system of sewage disposal, 427
Elevation, head of, 57
Emergency sanitation, Reevozone charges for sewers, 422
Enamelled channels, white, 239
Enteric fever, disinfecting after, 423
Estimate of amount of sewage, 30
Estimate of sewage and rainfall combined, 32
Eucalyptus oil, antiseptic, 420
Eucalyptol powder and oil, disinfecting, 420
Evaporation, disposal of sludge by, 535
Examination of drains, 418
Examining eyes in traps, 291
Examples, worked,—
—— angular section, channel with, 180
—— horse power, water supply, 196
—— mains, water supply, 194
—— services, water supply, 185
—— size and self-cleansing velocity, stoneware pipes, 175
—— slope, stoneware pipes, 179
—— water supply, cast and wrought iron pipes, 182
Excavating trenches for drains, 220
Exeter, septic tank at, 509–512
Extractors, sewer-gas, 273–275
Eytelwein on the flow of liquid in channels, 42

F.

Fall, maximum, 33
—— minimum, 33
Fans, power of, for forcing combustion, 567
Farms, sewage, 429, 434–438, 553
Ferozone, 456
Field's flushing syphon, 367, 369
Filters for purifying sewage, 439
—— Garfield, 505
—— Lowcock's, for biological treatment of sewage, 478
—— Scott-Moncrieff's, for biological treatment of sewage, 481
Filtration, system of disposal of sludge, 427
—— constant aëration required, 438
—— farm at Hitchin, 438
—— intermittent downward, 437
Fittings for drain cleansing, 227
Flaps to outlets, 305, 362
Floating arms, 442

Flood water, exclusion of, from sewers, 32
Flow of liquid in pipes and open channels, 37–56
Flush, good, necessary for traps, 290
Flushing, 34
Flushing drains, 365, 418
—— Adams's flushing syphon, 368
—— Ducketts' automatic tippers, 372
—— Field's patent syphon for, 367, 369
—— fire engine for, 373
—— manholes for, 373
—— Merrill's flushing syphon and tank, 350
—— Miller's flushing syphon, 370
—— movable tanks, 373
—— order of, 374
—— syphons for, 350, 364, 367–372
—— water for, 365
—— velocity, diagrams for effect of, 372
Forced draught, 566, 551, 557
Forcing combustion, power required, 567
Foreshore, outfall pipes on, 236
—— sewage deposits on, 428
Form of traps, special, 290, 291
Formalin, 419, 421
Formula for fall with limiting velocity, 34
Formulæ for flow of water in pipes and open channels, 37–56
—— Darcy and Bazin, 43
—— Ganguillet and Kutter, 47
—— —— Author's form of, 54
—— —— Flynn's modification of, 53
—— relative accuracy of, 52
—— hydraulic tables in connection with. *See* List of Tables in front of book
Foul air, organic matters in, 261. *See also* Sewer-Gas
Foul drains, admission of surface water to, 286, 295
Foundations, drainage under, 392
—— for chimney shafts, 590
—— for sewers, 232–236
French drains. *See* Subsoil Drainage
Fryer's patent destructor, 546
Furnaces, refuse. *See* Destructors

G

Galileo on flow of liquid in channels, 38
Galton, Sir Douglas, paper by, 475
Ganguillet and Kutter's formula, 47
—— Author's form of, 54.
—— Flynn's modification of, 53
—— graphic solution of value of (c), 49
—— relative accuracy of formulæ, 52
Garbage, 570, 573
Garfield filter for biological treatment of sewage, 505
Garrett's earth closet system, 6
Gasket, tarred, for joints, 209
Gas-pipes, test for leakage in, 410
Gauging a stream, 70
Germs of zymotic disease, 1, 2
Glasgow Sewage Works, 446–450
Gloucester, disposal of sewage at, 454
Goux principle, 6
Gradient and velocity of flow, 33
Grandi, on flow of liquid in channels, 39
Grease traps, 301
—— the Author's pattern, 302
—— Hellyer's, 301
—— "Loco," 302
—— Winser's flushing rim, 303
Grout, 202
Guano, native, 455
Guglielmini, 39
Gullies, Cartwright's, 382
—— Crosta's, 381
—— Dean's, 382
—— Ducketts', 383
—— Hagen's, 382
—— Turner and Croker's, 380
—— Lovegrove's, 383
—— Lowe's, 380
—— Newton's street, 380
—— Stokes', 383
—— Sykes', 383
Gullies for stables, 304
—— Broad's, 305
—— Colonel Moore's, 304
Gutters, eaves, types of, 376

H.

Hagen, on flow of liquid in channels, 39
Halpin's thermal storage, 583
Harbours, discharge of sewage into, 428
—— land-locked, 428
Head of elevation, 57
Head, loss of, due to—
—— bends, angular, 62
—— bends, circular, 62
—— elbow in stream, 62
—— orifice of entry, 59
—— resistance of pipe, 57
—— velocity, 59
Head of pressure, 57
Headers or cross drains, 389
Heat, utilization of, from destructors. *See* Destructors
Height of chimneys for destructors, 590
Height or afflux to which river is raised by obstruction, 69
Hendon, biological treatment of sewage at, 496, 514
Hereford, refuse destruction at, 559
Hermite process of sewage treatment, 465

High-level sewers, mode of connecting with low-level, 15
Hitchin, irrigation farm at, 438
Horse power, water supply, example of application of formulæ, 196
House refuse, disposal of, 529–604
—— amount of, 529
—— collection and removal, 529
—— cost of removal, 533
—— putrefaction of, 532
—— methods of disposal, 532
—— mechanical sorting, 533
See also Destructors
House drainage, 278
—— socket pipes, and connections for, weight of, 246, 247
House drains, air inlet for, Elliott's patent, 268
—— inclinations for self-cleansing, 34
House inspection, 409
Humphreys (Captain) and Abbot (Lieut.) on the flow of liquid in channels, 42
Hydraulic gradient, 64
—— lime, 201
—— mean radius, or depth, 40, 65
—— memoranda and tables, 57–174
—— tables, 81 (*vide* detailed list of, in front of book)
—— or water test, 412
Hydraulic memoranda and formulæ, 57–174
—— circular bends, 62
—— discharge of syphons, 65
—— discharge of water over a notch or weir, 67
—— egg-shaped sewers, 66
—— effect of bends on pipes and rivers, 62
—— gauging a stream, 70
—— head of elevation, 57
—— hydraulic mean depth, 65
—— inclination, sine of, 64
—— loss of head, 57
—— loss of head due to velocity, 59
—— —— orifice of entry, 59
—— —— at elbow, 60
—— pressure of liquids, 57
—— separating weirs, 71
—— to raise a river a certain height by a weir, 69
—— triangular notch, 71
—— velocities, destructive, 76
—— velocities, mean velocities from maximum surface velocities, 75
—— velocities, mean surface and bottom, 74
—— velocities, relation between mean and surface, 74
—— velocity, measurement of, 72
—— water, abrading and transporting power of, 77

I.

Inclination of house drains for self-cleansing, 34
—— sine of, 64
Increase of population, 30
Infectious disease, sites of, to be recorded, 419
Inspection of houses, 409
—— arm for sewers, 15
Inspection pits. *See* Manholes
Interception, excreta manufactured into manure at Rochdale, 9, 539
—— adopted to avoid large expenditure, 9
—— objections to, 10
Interception system of sewerage—
—— cesspits, 4
—— cost of removal, 8
—— earth closets, 6
—— middens, 5
—— pails and tubs, 5
—— soak pits, 5
—— temporary latrines, 7
—— drains necessary, 9
—— Goux principle, 6
Intercepting sewers, 15
—— traps, 276, 291. *See also* Traps
Interceptor, Doulton's, 294
—— Light's, 297
—— "Kenon," 296
—— "Loco" main, 297
—— Stiff's, 295
—— Sykes', 297
See also Traps, Intercepting
Interceptor, storm water, 31
International process for sewage disposal, 456
—— at Mangotsfield Sewage Disposal Works, 456
Invert blocks, 232B
Inverted syphons, 17
Iodine, 419
Ipswich, disposal of sewage at, 465
Irrigation, acreage, 436
—— broad, distribution over land, 434
—— system of disposal of sewage, 427, 429
—— farm, Beddington, 435
—— —— Hitchin, 438
—— —— Portswood, 553, 580, 583
—— farms, climates suitable for, 437
—— preparation of land, 435
—— soils suitable for, 429
—— capacity of soils to decompose sewage, 429
Izal and Izal powder, 420

J.

Johnson's patent sludge press and Hutchinson's pneumatic system, 538
Joints, pipe, 209–218
—— Ames and Crosta, single seal, 216
—— —— the double seal, 217

Joints, pipe—*continued*
—— Button's patent "Secure," 211
—— Doulton's self-adjusting, 212
—— Green's patent true invert, 215
—— Hassall's improved patent safety, single lined, 213
—— —— double lined, 213
—— the "Loco" drain joint, 215
—— saddle, 209
—— Stanford's, 209
—— Sykes' patent, 218
—— Tyndale's double seal, 212
Joints, use of clay as a material for, 209
Junction pits, 239
Junctions not to be at right angles, 27

K.

KANPHORKALK disinfecting powder, 420
Keirby's patent sewage mixer, 442
Kresyline, liquid for disinfecting, 420
Kühlmann, on the flow of liquid in channels, 42
Kutter, formula of, 47

L.

LAMPHOLES, 236
Land, preparation of, for sewage irrigation, 435
—— used for sewage filtration, aëration of, 438
—— capacity of, to purify sewage, 437
Latrines, great variety of, 310
—— Jennings's automatic, &c., 310–312
—— Bowes, Scott, and Western, 310
—— Doulton & Co., 310
—— Macfarlane's, 310
—— position of, &c., 309, 310
Laundries, drainage of, 260
Law relating to sewerage and drainage, 13
—— as to removal of refuse, 529
Laying drains, methods of, 218
—— sewers. *See* SEWERS
Lead pipes, connections for w.c.'s, 254
—— waste pipes, 255
—— connection with stone-ware pipe, 255
—— variety of joints, 255
Levels, method of connecting high and low level sewers, 15
Liernur system, 3
Lifting apparatus, sewage, 17–27, 571, 580
Lightning, effect of, on destructor shafts, 574
Lime process for sewage disposal, 445
—— and alumina process for sewage disposal, 446
—— and sulphate of iron process for sewage disposal, 445
Limiting velocity, formula for fall with, 34
Liquids, flow of, in pipes and open channels, 37–56
—— Darcy and Bazin's formula, 43
—— Ganguillet and Kutter's formula, 47
—— —— Author's form of, 54
—— —— Flynn's modification of, 53
—— —— graphic solution of the value (c), 49
—— relative accuracy of formulæ for, 52
—— history of the development of our knowledge of the, 38
—— hydraulic tables. *See* LIST OF TABLES in front of book
—— pressure of, 57
Liverpool, disposal of sludge at, 532
—— Manlove, Alliott & Co.'s refuse destructor at, 550
Local authority, duty of, to ventilate, 265
"Loco" drain badger, 224
London, Metropolitan Sewage Works, 428, 445, 446, 469, 470, 473, 511
London water supply, 426
Lowcock's filter for biological treatment of sewage, 478
Low level sewers, mode of connecting with high level, 15.
Lynde's principle of draining by deflection, 27

M.

MADE ground, sanitary notes on, 407
Magnetic spongy carbon, 456
Mains, water supply, example of application of formulæ, 194
Manchester, disposal of sludge at, 535
Mangotsfield Sewerage and Sewage Disposal Works by the International process, 456
Manhole cover, oval ventilating, 268
—— covers, 239–241, 268
Manholes, 16, 236, 373
—— rock-concrete, 237, 238
—— for flushing drains, 373
—— at junctions, 16
—— straight lines between, 16
Manlove, Alliott & Co., sludge press, 550
Manure, excreta manufactured into, at Rochdale, 9, 539
—— at Southampton, 573
Manure, sludge, 538
Massachusetts, experimental investigations by the State Board of Health on biological disposal of sewage, 475
—— precipitants, comparative advantages of different, 465
—— filtration, 439
Maximum flow of sewage, 29
Mean and maximum velocities, ratio of (Prony), 75
Mean, surface, and bottom velocities (Bazin), 74
Mean and surface velocities, relation between, 74

Mean velocities from maximum surface velocities (Flynn), 75
Measurement of velocity of stream, 72
Mica flap inlet ventilator, 280
Middens, 5
Miller's flushing syphon, 370
Minimum fall for foul water drains, 33
Mixers, sewage, 442
Moore's, Col., process for curing damp walls, 404
—— grease trap, 302
—— stable trap, 304
Mortar, cement, 201
—— blue lias lime, 202
Mortar, manufacture of, from clinkers, 551
Motive power, production of, from waste heat of destructors, 544, 575
Moule's earth closets, 6
Movable tanks for flushing drains, 373
Muriate of iron process (Dale's) for sewage disposal, 465
Multiple closets, 325

N.

NATURAL Purification Company's system for disposal of sewage, 451
Natural soil, sanitary notes on, 408
Neville, on the flow of liquid in channels, 42
Newport, Rhode Island, disposal of sewage at, 482–488, 519
Night soil depôts, 22
Nitrification, theory of, 431
—— distribution of nitrifying organisms, 432
—— Rothampstead experiments on, 431
Northallerton, purification of sewage at, 505
Notch, triangular, formula for discharge of, 71
Notch or weir, formula for discharge of water over, 67
Nuneaton, disposal of sewage at, 452, 453

O.

OBSERVATIONS, float, 427
Obstructions, in sewers, how removed, 226
Obstructions in river, increased velocity due to, 69
Oldham, refuse destruction at, 553
Open channels, flow of liquid in, 37–56
Order of flushing drains, 374
Organic matters in foul air, 261
Orifice of entry, loss of velocity due to, 59
Osmic acid, 419
Outfall pipe, steel, 254
Outfall pipes on foreshore, 236
—— position of, influence on passage of sewer-gas, 266
Outfalls, sewer, 16, 17, 254, 429
Outside gullies, ventilation of, 286
Overflow from lead safes, 362
Oxychlorogene, liquid for disinfecting, 420
Oxygen system of sewage purification, 496D–505
—— adaptability of existing works for, 504
—— cost of, 505
—— tanks for, 502
—— no large buildings and no heavy machinery needed, 503
—— no skilled labour, 504
Oxynite, for sewage precipitation, 455

P.

PAILS and tubs, 5
Partially separate system, 3, 12
Paving materials for stables, 256–260
Paving, tar, 549–551, 575
Peat, effect of moisture on, 385
Peaty soil, drainage of, 394
Penstock chambers, 17
Peppermint and smoke tests, instructions for, 414
Perchloride of iron, 420
—— of mercury, 419
Perfect purifier and Jeyes' liquid for disinfecting, 420
Permanganate of potash, 420
Permanganic acid, 288F
Phenol for disinfecting purposes, 420
Pinewood and eucalyptus powder, 420
Pipe, resistance of, to flow of liquid, 59
Pipe-joint, Ames and Crosta, single seal, 216
—— double seal, 217
—— Button's patent "Secure," 211
—— Doulton's self-adjusting, 212
—— Green's patent true invert, 215
—— Hassall's improved patent safety, single lined, 213
—— double lined, 213
—— "Loco" drain joint, 215
—— Paragon patent pipes, 215
—— saddle, 209
—— Stanford's, 209
—— Sykes' patent, 218
—— Tyndale's patent, 212
Pipe-joints, how made, 209
—— clay as a material for, 209
Pipe-laying, method of, 224
—— "Loco" drain badger, 224
Pipes, description used for foul drains, 203
—— concrete, 207
—— discharge of (Bailey Denton), 34
—— forms of, 204
—— granite stoneware, sanitary, 205
—— granitic stoneware, 3 feet long, 206
—— joints, how made, 209
—— "Loco" inspection shaft for, 207

Pipes, special connections, 206
—— Standard access, &c., 206
—— stoneware maximum diameter, 204
—— tested, 203
—— thickness of, 204
Pipes and open channels, flow of liquid in, 37–56
Pipes, cast-iron. *See* CAST-IRON DRAIN PIPES
—— rain-water, types of, 377
Pipes for ventilating shafts, 275
Pipes, lead, connection with stoneware pipes, 255
—— connection for w.c.'s, 254
—— variety of joints, 255
—— waste pipes, 255
Pipes, stoneware, causes of breakage of, 225
—— chokage of, 226
—— temporary obstruction, how removed, 226
Pitot on flow of liquid in channels, 39
Pits, disconnecting, 277
—— catch, 378
—— junction, 239
—— inspection. *See* MANHOLES
—— soak, 5
—— cess, 4
Pixine, liquid for disinfecting, 420
Plan of drains, 403
Plank foundation of sewers, 235
Plugs, drain, 412
—— Jones's pipe stopper, 413
Plugs and wastes, 362
Pneumatic, Shone's hydro-pneumatic ejector, 17–23, 571, 580
—— system, sewerage of Rangoon on, 22–24
—— Johnson and Hutchinson's, 539
Poisons, septic, 540
Polarite, 456
Population, increase of, 30
Portland cement, 199
Portswood, sewage farm at, 553, 580, 583
Potash, 419
Precipitants, comparative advantages of the different, 465
Precipitation agents, 444
Precipitation system of sewage disposal, 427
Precipitation, or chemical treatment of sewage, 441
—— Mr. Dibdin's opinion on, 444
Precipitation by electrolysis, 469
—— Sir H. Roscoe's report on, 472
Pressure at any point in a liquid, 57
—— head of, 57
—— on solid bodies, 597
Preventers. *See* WASTE
Public conveniences, Bolding's "Laydas" circular pedestal, 348
—— underground, 286
—— ventilation of, 287
Pumping and lifting sewage, 17–27, 571, 580
Purification of air in sewers, 422. *And see* SEWER VENTILATION
Purification of sewage by bacterial oxidation and forced aëration by Colonel Geo. E. Waring, 514
Purity, standard of, 427

Q.

QUANTITY of sewage, estimate of, 30.

R.

RAINFALL drainage, use of old sewers for, 12
Rainfall, effect of, on sewage irrigation, 437
—— admission of into sewers, 30, 31, 33
Rain-water pipes, types, 377
Ramps, to subdivide sewers, 15, 266
Rangoon, sewerage of, 22–24
Reeves' system of sewer ventilation, 288
"Reevozone" disinfectant, 422
Refuse Disposal Company, 533
Refuse, house, collection of, 529–532
—— analysis of London ashbin, 541
Refuse destructors. *See* DESTRUCTORS
Regulators, oil brass closet, 334
—— Underhay's water waste preventer, 334
—— waste-preventing, under seats, 332
Relation between mean and surface velocities, 74
Relations between sewage and the effluents from chemical precipitation to the growth of bacteria and algæ, 467
Removal of excrement (dry earth system), cost of, 8
Resistance of pipe to flow of liquid, 59
Richmond Main Sewerage Works, 450
Rideal, Dr., on sewage purification, 492
Ridge and furrow system of irrigation, 435
River raised a certain height by a weir, 69
Rivers, pollution of, by sewage, 427
—— accumulation of sewage in, 428
Road gullies. *See* GULLIES
—— sweepings, 533
Roads, drains under, 403
—— surface water from, 375
Robinson, Professor H., on Nitrification, 432
Rochdale, refuse destruction at, 539, 558
—— disposal of sludge, 536, 539
—— sewerage of, 16

Roots in subsoil drains, 403
Rust-joint, 253
Rust pockets, 275

S.

SALFORD, experiments in sewage purification at, 506–509
—— disposal of sludge at, 535
Sand, for mortar and concrete, 201
—— shifting, pipes laid in, 236.
Sanitary maxims, 424
Sanitary notes on—
—— aërial deodorants, 420
—— analysis of subsoil water, 418
—— antiseptics, 419
—— Burnet's smoke drain tester, 417
—— Calvert's carbolated creosote, 422
—— chloride of lime, 422
—— Condy's fluid, 422
—— the Champion fumigator, 416
—— deodorizer, but not an antiseptic, 420
—— disinfectants, method of application of, 422, 423
—— —— powerful or germicide, 419
—— —— use of, 420
—— —— weak, 419
—— disinfecting, powders and liquids for, 420
—— formalin, 421
—— izal, 420
—— drain grenades, 417
—— drain testing, 409
—— drain plugs, 412
—— the Eclipse smoke generator, 415
—— examination of drains, 418
—— flushing drains, 418
—— house inspection, 409
—— hydraulic or water test, 412
—— influence of subsoil water on health, 408
—— Jones's patent pipe stopper, 412
—— Kemp's patent drain tester, 417
—— made ground, 407
—— natural soil, 408
—— old culverts to be destroyed, 418
—— Pain's smoke rockets, 417
—— peppermint and smoke tests, instructions for, 414
—— Reevozone, 422
—— sites of infectious diseases to be recorded, 419
—— water mains periodically tested, 418
—— steam, admission of, to sewer, 408
—— subsoil drainage, necessity for, 418
—— the Tyndale asphyxiator, 416
—— water supply, pipes disconnected from sewer, 418
—— the Watts' asphyxiator, 416
—— powder, Jeyes', for disinfecting, 420
Sanitary science, great advances in, 2
Sanitas powder for disinfecting, 420
Saturation, line of, between drains, 389
Scientific principles of sewage purification, 497
Scott-Moncrieff's system of sewage disposal, 491, 526
Screen, sewage, 496B
Screw current meter, 73
Sea, discharge of sewage into, 427
—— water, effect of, on sewage, 428
Seaside towns, sewage of, 428
Section, cross, area of, 29
Self-cleansing inclinations, house drains, 34
Separating weirs, action of, 71
Separate system of sewage (absolutely), 3
—— partially, 3
Septic poisons, 540
Septic tank system of sewage disposal, 509
Services, water supply, example of application of formulæ, 185
Settling tanks, general form of, 433
—— Dundrum, 434
—— the Dortmund, 434
Sewage, amount of, 29
—— adequate means for removal necessary, 3
—— definitions of, 2
—— disposal, systems for. *See* SEWAGE DISPOSAL
—— estimate of amount of, 30, 32
—— lifting apparatus, 17–27, 571, 583
—— maximum flow of, 29
—— mixer, Keirby's, 442
—— precipitation, 427
—— pumping and lifting, 17–28, 571, 580
—— question of admission of rain-water into, 30
—— screens, 496B
—— water supply as guide to amount of, 30
Sewage disposal, processes and systems—
—— A B C, 455
—— Amines, 445
—— bacteriolysis, 427
—— Conder's sulphate of iron, 463
—— Dale's muriate of iron, 465
—— discharge into sea or tidal estuary, 427
—— dry earth, 427
—— electrolysis, 427
—— filtration, 427
—— the Garfield filter, 505
—— the Hermite, 465
—— the International, 456
—— influence of tidal currents on, 428
—— irrigation, 427
—— lime, 445
—— lime and alumina, 446
—— lime and sulphate of iron, 445
—— precipitation, 427
—— Spence's alumino-ferric, 450
—— the Oxygen system of, 496, 496D

Sewage disposal, processes and systems—*continued*
—— the Scott-Moncrieff system, 526
—— septic tank system, 509
—— the Natural Purification Company's system, 451
—— tidal estuary for, 427
—— the Universal Sewage Purification Co. (The "Ives" patent), 453
—— variety of processes, 444
Sewage disposal at, Aylesbury, 455; Barking, 445, 446, 511; Burnley, 445; Beddington, 435; Birmingham, 445; Bradford, 454; Bristol, Mangotsfield, 456–462; Chichester, 464; Coventry, 537; Crossness, 445, 446, 469, 470; Glasgow, 446–450; Gloucester, 454; Hendon, 496, 514; Hitchin, 438; Ipswich, 465; Newport (U.S.A.), 482–488; Northallerton, 505; Nuneaton, 452, 453; Richmond, 450; Rothampstead, 431; Salford, 506–509; Southampton, 570–583; Sutton, 496; Wimbledon, 537; Wolverhampton, 445, 481, 490, 496
Sewage, decomposing, dangerous, 261
Sewage farms, 429, 434–438, 583
Sewage Purification. *See* SEWAGE DISPOSAL, &c., *ante*
Sewerage, 11–36
—— absolutely separate system of, 3, 11
—— combined system of, 3
—— choice of system, 11
—— estimate of amount of sewage to be dealt with, 30
—— estimate of sewage and rainfall combined, 32
—— general principles of, 14
—— interception system of, 4
—— Liernur system of, 3
—— modification of combined system, excluding subsoil water, 3
—— partially separate system of, 3
—— pneumatic system of, 3, 22
—— pumping and lifting sewage, 17
—— water carriage system of, 3
—— water supply as a guide to, 30
—— of Brighton, 15; Bristol, 15; Liverpool, 15; Metropolitan, 16, 31; Rangoon, 22; Rochdale, 15, 16, 22; Southampton, 12, 22, 570–583; Warrington, 22; Wimbledon, 12
Sewerage and Sewage disposal works at Southampton, 570, 576
Sewer-gas, Dr. Alessi's experiments, 261
—— Mr. T. Parry Laws, and Dr. F. W. Andrews, experiments of, 262
—— Mr. H. Alfred Roechling, C.E., defective drainage, 265
—— Dr. I. Spottiswoode Cameron, defective drainage, 265
—— Dr. Louis Parkes, opinion of, 262
—— Sir George Buchanan, opinion of, 262
—— effect of wind on, 266
Sewer-gas, influence of atmospheric forces on, 288B
—— special arrangements for dealing with, 272
—— upward flow of injurious, 15
See also SEWER VENTILATION, *post*
Sewer outfalls, 16, 17, 254, 429
—— outlets, sea coast, types of, 16
—— overflow outlets, 16
Sewer ventilation, 261–275, 288
—— Adams's system, 273
—— Brown's (Mr.) experiments, 288C
—— charcoal ventilator, 273
—— chemical deodoriser, 273
—— W. Santa Crimp's (Mr.) experiments, 273
—— extractors and destructors, Webb's patent, 275
—— high shafts for, 272
—— influence of atmospheric forces, 288B
—— Keeling's destructor, 273
—— machinery, 275
—— points to be observed, 266
—— the Reeves system, 288
—— shafts for, 269, 272, 275
—— velocity in shafts, 270
—— water injection, 275
See also SEWER GAS, *ante*
Sewers, 13
—— access pipe to, 208
—— adequate foundation, 233
—— admission of rainfall into, 30, 31
—— admission of small and impure rainfalls in, 31
—— area of cross sections of, 29
—— arrangement of, 14
—— bricks for, 228
—— bursting of, 15
—— concrete, 233
—— connection of house drains with, 27
—— construction of, 232.
—— cross sections of, 29
—— depth of, 16
—— draining of subsoil water from exterior of, 391
—— dimensions and brickwork required, 231
—— egg-shaped, 66, 67, 160, 173, 229
—— —— old form, 66
—— —— new form, 66
—— —— Jackson's peg-top section, 67
—— fall of (maximum and minimum), 33
—— flood water, exclusion of, from, 32
—— flushing of. *See* FLUSHING
—— inverted syphons for, 17
—— intercepting large and pure rainfalls from, 31
—— intercepting, 15
—— in wet ground, 232
—— levels of, 15
—— laid in sand, 236
—— manholes for, 16. *See* MANHOLES

Sewers—*continued*
—— method of forming in presence of water, 234
—— obstructions in, how removed, 226
—— plank foundation for, 235
—— penstock chambers, 17
—— quantity of paved surface (Table 2), 35
—— ramps in, 15, 266
—— storage tank, 16
—— size and inclination of main house drains, 36
—— sizes of, 35, 36
—— sizes of, combined system, 35
—— springs as obstacles in laying, 234
—— steam, admission of, 408
—— syphon drops in, 15, 16
—— thickness of concrete sewers, 233
—— traps for. *See* TRAPS
—— valves for, 16
—— velocity of flow, 33
—— velocity and discharge of circular, 128, 159
—— velocity and discharge of egg-shaped, 160–173.
—— ventilation of, 265–275, 288
—— wearing action in, 15
Sewers and drains, extra fall at junctions and curves, 15
Shafts, ventilating, 269, 275
—— rust pockets for, 275
—— size of, 275
Shifting sands, pipes laid in, 236
Shone, pneumatic ejector, 3, 17–22, 571, 580
—— advantages of, 21
Shoreditch, electric light at, 583
—— refuse destruction at, 583
—— results obtained from destructor, 587
Shoring trenches, 220–223
Sight rails for laying drains, 219
Silt basins, 390
Silt in subsoil drains, 402
Sine of inclination, 64
Simple ventilation, 268
Single drainage, 276
Sinks, traps for, 305
—— anti-D, 307
—— bell, 307
—— double seal, Jennings's, 307
—— Jennings's bell, 306
—— syphon, 307
—— Tye and Andrew, 307
Sinks, slop, Dent and Hellyer, 350
—— —— Tylor and Sons, 350
—— clean water supply to, 326
—— scullery, 353
—— Duckett's fittings for, 355
—— pantry, 355
Sites for barracks, 385
Sites of infectious disease to be recorded, 419
Size and inclination of main house drains, 36
Size and self-cleansing velocity, glazed stoneware pipes, example of application of formula, 175
Slop water-closets, 324
Slope required for glazed stoneware pipes, example of application of formula, 179
Sludge, disposal of, 535
—— by destruction, 540, 546, 555
—— by evaporation, 535
—— by mechanical treatment, 536
—— by Johnson and Hutchinson's patent pneumatic system, 539
—— cost of plant, 537
—— formula for weight of, 538
—— manure, 538
—— presses, Johnson's patent, 536
—— —— Manlove, Alliott & Co., 536
—— utilization of, 538, 539
Sludge, disposal of at, Ealing, 546; Leyton, 555; Liverpool, 532; Southampton, 570–583; Salford, 535; Manchester, 535; Rochdale, 536; Coventry, 537; Birmingham, 535; Wimbledon, 537
Soak pits, 5
Soda, 419
Softening of water, 426
Soil, best for sewage irrigation, 429
—— power of, to decompose sewage, 429
Soil pipe, ventilation of, 279
—— alternative method of, 279
—— fresh air inlet to, 279
Soil pipes, vertical, cast-iron, 250
—— —— lead, 249
—— "Loco" deflector bend for, 252
—— size of, 251
—— syphons at foot of, 254
Soils, suitability of, for sewage irrigation, 429
—— power of, to decompose sewage, 429
—— distribution of nitrifying organisms, in, 432
—— clay, 392
—— injurious effects of wet, 385
See SUBSOIL DRAINAGE, and 407, 418
Southampton, construction of egg-shaped sewers at, 232
—— refuse destruction at, 573
—— sewage disposal of, 570–583
—— sewerage of, 12, 576
—— surface water drains, 232B
Springs, an obstacle in forming culverts, 234
Square roots, Table of, 174
Stability of chimney shafts, 599
Example of method of calculating, 600
Stables, gullies for, 304
—— —— Colonel Moore's, 304
—— —— Broad's, 305
—— how drained, 256
—— materials for paving, 257–260
Stains, removal of, from lavatory basins, 361
Steam, admission of, to sewer, 408

Steam boilers, artificial or forced draught for, 566
Steel outfall pipe, 254
Steep gradients, stoneware pipes, precautions for, 15
Stone or French drain, 401
Stoneware pipes—
—— causes of breakage of, 225
—— chokage of, 226
—— temporary obstruction in, how removed, 226
Storage tank, 16
Storm water interceptor, 31
—— provision for, 15, 30, 32
Stream, measurement of velocity of, 72
Street gullies. *See* GULLIES
Strength of concrete, 594
Subsoil drainage, 385–406
—— air drains, 392
—— arrangement of drains, 388
—— boggy land, 402
—— brushwood, 402
—— clay soil, 392
—— Colonel Moore's process for curing damp walls, 404
—— —— advantages of, 405
—— —— general remarks on, 405
—— depth of drains, 387
—— direction of drains, 389
—— distance between drains, 389
—— execution of, 394
—— failure of drains, 402
—— —— roots of trees, 403
—— —— silt, 402
—— —— vermin, 403
—— fall for drains, 388
—— flushing drains, 392
—— general report of the Commission on Improving the Sanitary Condition of Barracks and Hospitals, 385
—— hand packing, 401
—— necessity for, 418
—— outlets to drains, 390
—— peaty soil, 394
—— pipe laying and method of, 399
—— pipes for, material and size of, 395
—— —— quality of, 397
—— —— junctions of, 398
—— plan of, necessary, 403
—— silt basin, 390
—— special, for footings, 393
—— special measures for underground buildings, 403
—— sumps, use of, 391
—— surrounding site of buildings, 392
—— trenches, bottom to be currented accurately, 395
—— —— depth of, 394
—— —— filling in, 399
—— —— filling in fine earth and its object, 400
—— —— filling in stones over pipes, 400
—— —— tools for excavating trenches, 395–397
Subsoil under buildings, 392
—— under foundations, 392
—— under railway embankment, 394
—— under roads, 403
—— water, analysis of, 418
—— influence on health, 408
Sulphate of iron process, Conder's, for sewage disposal, 463
Sulphate of copper, 420
—— of iron, 420
—— of zinc, 420
Sulphuric acid, liquid for disinfecting, 420
Sumps, use of, 391.
Surface water, collection of, 375–384
—— admission to foul drain, 287, 384
—— buddle hole, 383
—— catchpits for, 378
—— —— combined system, 379
—— —— separate system, 378
—— connection with foul water drains objectionable, 375
—— down pipes, joints in, 375
—— drains for, 378
—— drains at Southampton, 232B
—— eaves gutters for, 375
—— gully for, Crosta's, 381
—— —— Ducketts', 383
—— —— Lovegrove's, 383
—— —— Newton's street, 380
—— —— Stokes', 383
—— —— Turner and Croker's, 380
—— —— Sykes, street and yard, 383
—— surface channels for, 375
—— traps for, Mason's or dip traps, 379
—— —— Cartwright's stench trap, 382
—— —— Dean's, 382
—— —— duplex cesspool, Hagen's, 382
—— —— Lowe's, 380
Sutton, biological treatment of sewage at, 496
Syphon drops, 15
Syphons, cast-iron pipes for, 254
—— flushing, 350, 364, 367–372
—— —— Adams's, 368
—— —— Field's, 367, 369
—— —— Miller's, 370
—— for sinks, 364
—— inverted, 17
—— loss of head due to, 65
Systems of sewage disposal. *See* SEWAGE DISPOSAL
Systems of sewerage. *See* SEWERAGE
—— —— comparison of, 9
—— —— choice of, for sewerage, 11

T.

TABLES, hydraulic memoranda and tables, 57–174. *See* LIST OF TABLES in front of book
—— of velocity and discharge of circular pipes, sewers, and conduits (Kutter's formula), 128–159

Tables of velocity and discharge of egg-shaped sewers (Kutter's formula), 160–173
Tank, storage, 16
Tanks, settling, general form of, 433
—— the Dortmund, 434, 502
—— Dundrum, 434
Tar paving, clinkers for, 549–551, 575
Taylor's earth closets, 6
Teale, Mr. Pridgin, sanitary maxims, 424
Temporary latrines, 7
Terebene for disinfecting, 420
Testing drains, 409–417
Thickness of concrete sewers, 233
Thermal storage, Halpin's, 583
Thymol, 420
Tidal currents, influence of, 428, 544
—— estuary for disposal of sewage, 427, 544
—— river, discharge of sewage into, 427, 544
—— valve for sewer, 16
Tides, neap, 428
—— effect of, on sewage outfalls, 428, 544
Timbering trenches, 220–223
Tools for excavating trenches for sub-soil drains, 395–397
Torricelli on flow of liquid in channels, 39
Town refuse, disposal of, 529–604. *And see* DESTRUCTORS, *ante*
Trade effluents, 502
Transporting and abrading power of water, 77
Traps, 289–308
—— anti-D, 307
—— ball-tide valve, 305
—— bell, 306
—— Bower sewer-gas trap, 318
—— deflecting traps, 298
—— disconnecting, 296, 298
—— examining eyes for, 291
—— failure of water-lock of, 289
—— flaps, 305
—— form of, 290
—— for sinks, 305. *See also* SINKS
—— foul water D trap, 291
—— good flush necessary, 290
—— grease, 301
—— intercepting, 291–300
—— Jennings's bell, 306
—— Jennings's double seal, 307
—— Mason's or Dipstone's, 290
—— Mooney's self-cleansing gully, 299
—— necessary evils, 289
—— object of, 289
—— position of, 290
—— self-cleansing, 291, 299
—— self-closing, 303
—— special forms of, 291
—— syphon, 307
—— tide valve, self-closing, 303
—— Tye and Andrew's syphon trap, 307
—— ventilating intercepting, 291
Traps, water-lock of, 289
Traps, grease, 301–303
—— Author's pattern, 302
—— Hellyer's, 301
—— "Loco" grease box, 302
—— Winser's flushing-rim, 303
—— intercepting, 260, 291–300
—— Buchan's patent, 293
—— cast-iron disconnecting, 298
—— Couzen's ball trap, 305
—— Doulton's sewer-gas interceptor, 294
—— Hellyer's, 292, 294
—— Ingham and Sons', 295
—— "Kenon" intercepting, 296
—— Light's quick-flush, 297
—— "Loco" deflecting, 298
—— "Loco" main intercepting, 297
—— Sankey's deep intercepting gully, 299
—— self-closing, 303
—— Stiff's interceptor sewer trap, 295
—— Sykes' sewer-gas interceptor, 297
—— Weaver's, 292
Traps, stable gullies, 304
—— Author's pattern, 304
—— Broad's, 305
—— Cottam and Willmore, 304
Trenches for subsoil drainage, 394
Triangular notch, formula for discharge of, 71
Trichloride, 419
Tunnelling, 223
Turpentine, oil of, 420
Typhoid bacilli, bearing of tubs and water-closets upon the prevalence of, 8
—— how introduced into system, effects of heavy rainfall on, 2
—— fever, bearing of tubs and water-closets upon the prevalence of, 8

U.

UNDERGROUND buildings, subsoil drainage of, 403
"Universal" Sewage Purification Co. (the "Ives" patent), 453
Underground conveniences, 286, 342
Urinals, lavatory fitments, &c., 335–374
—— automatic flushing apparatus for, 349
—— Bolding's "Laydas" circular pedestal, 348
—— Crapper's flushing cistern, 350
—— Hellyer's, 341
—— "Holborn" trapped, 341
—— interior, 339
—— Jennings's flushing tank, 349
—— Merrill's flushing syphons and tanks, 350
—— public conveniences underground, 342
—— three classes of, 335

Urinals, lavatory fitments, &c.—*continued*
—— trough, Doulton's flush-down, 338
—— Tylor's patent basin, 341
—— Twyford's, 342
—— Twyford's flushing syphon cistern, 350
Utilization of "destructor" clinkers, 545, 549–551, 575
—— sewage sludge, 535
—— waste heat from destructors. *See* DESTRUCTORS, *ante*

V.

VALUE of sewage, 437
Valve, ball tide, 305
Valves, Beaumont's, with Cregeen's air inlet cover, 280
Valves, self-closing, or tankard, 16
—— under seat of water-closets, 327
—— waste-preventing, fixed in cisterns, 328
Vegetable refuse injurious to health, 1
Velocity and discharge of circular sewers, pipes, and conduits, calculated by Kutter's formula, 128–159
—— —— egg-shaped sewers, calculated by Kutter's formula, 160–173
Velocity diagrams for effect of flushing in drains, 372
—— of flow and gradient, 33
—— increased by obstructions in river, 69
—— loss of head due to, 59
—— limiting, formula for fall with, 34
—— required to prevent deposit in sewers, 79
—— required to move rounded stones or shingle, 79
—— of stream, measurement of, 72
Velocities, destructive, 76
—— mean surface and bottom, 74
—— mean and maximum, ratio of, 75
—— mean and maximum, ratio of (rivers of largest class), 75
—— mean from maximum surface velocities (Flynn), 75
—— mean and surface, relation between, 74
Ventilate, duty of local authority to, 265
Ventilating openings to water-closet, apparatus, 319
—— manhole cover, oval, 268
—— shafts, 269
—— shafts, pipes for, 275
—— rust pockets for, 275
Ventilation, 260—288F
—— alternative method of, 279
—— double for sewers on steep slopes, 15
—— of drains of blocks of enclosed buildings, 286
—— of drains under buildings, 286
—— of outside gullies, 286
—— of sewers. *See* SEWER VENTILATION
Ventilation of soil pipe, 279
—— simple, 268
—— and traps, 265
Ventilator, charcoal, 283
Ventilators, Boyle, Kite, Sugg's, &c., 281
Venturi on the flow of liquid in channels, 41
Vermin in subsoil drains, 403
Voeckler, Dr., researches of, 429

W.

WALLS, dampness in. *See* DAMP WALLS
Waring, Colonel Geo. E., investigations of, 482
Warner's patent "Perfectus" destructor, 553
Wash-out closets. *See* WATER-CLOSETS
—— down closets. *See* WATER-CLOSETS
Washers, plugs and wastes, 362
Waste-preventing cisterns, 330
Wastes from sinks, baths, &c., 283
Water, abrading and transporting power of, 77
—— contamination of, by sewage, 426
—— discharge of, over notch or weir, 67
—— for flushing drains, &c., 365
—— lock of traps, 289
—— mains to be periodically tested, 418
—— meter, Deacon's, 418
—— method of forming culverts in, 234
—— subsoil, analysis of, 418
—— supply, London, 426
—— —— supplementary high pressure, 23
—— surface. *See* SURFACE WATER
Water carriage. *See* SEWERAGE
Water-closets, clean water, 313
bracket, hygienic, Hellyer's, 321
—— "Closet of the century," 322
—— Ducketts' pedestal, the "Clencher," 316
—— essentials of a good water-closet, 313
—— Jennings's and trap, 314
—— "Lambeth," 315
—— "Métropole," 317
—— pan closet, 313
—— pedestal, 317
—— "Scientia," 322
—— "Self-ventilating safety," 320
—— Shanks's "Compactum," 316
—— "Twycliffe" syphon pedestal, 317
—— Twyford's "Deluge," 316
—— Twyford's, 315
—— Tylor's, 314
—— Underhay's, 314
—— valve closets, 314
—— valveless, the "Hopper," 314
—— wash-down, 316
—— wash-out or flush-out, 315
Water-closets, slop water, 324

Water-closets, slop—*continued*
—— advantages over clean water, 325
—— Ducketts', 324
—— multiple, 325
—— the "Perfect," 325
Water-closets, clean water supply to, 326
—— Crapper & Co., 331
—— Doulton's vacuum water waste preventer, 330
—— Ducketts' A 1 stoneware, 316
—— oil brass closet regulators, 334
—— Shanks's reliable improved, 331
—— "Stafford" syphon cistern, 331
—— syphon plunger cistern, 332
—— Twyford's national, 331
—— Tylor's waste-preventer, 333
—— Underhay's waste-preventer, 334
—— valves under seats of w.c.'s, 327
—— "Westminster," 331
—— Winn's "Acme" syphon cistern, 331
—— waste-preventers and regulators, 328
—— waste-preventing cisterns, 330
—— waste-preventing regulators, fixed under seats, 332
—— waste-preventing valves fixed in cisterns, 328
Water supply with cast-iron and wrought-iron pipes, example of application of formula, 182
Water supply, a guide to estimate of amount of sewage, 29, 30
Water supply pipes to be disconnected from sewer, 418
Water supply, method of ascertaining the sizes for the supply pipes to a house, 185
—— to closets and sinks, &c., 326
Water test for drains, 412
—— waste preventers and regulators, 328
Wearing action in sewers, 15
Weir, to raise a river a certain height by, 69
Weirs, separating, action of, 71
Weisbach on the flow of liquid in channels, 42
Wet ground, sewers in, 232
—— soils, injurious effects of, 385
Wetted perimeter, 65
Wimbledon sewage works, 537
Wind, effect of, on sewer-gas, 266
—— pressure on chimney shafts, 595
Wolverhampton, treatment of sewage at, 445, 481, 490, 496
Wrought-iron piping, 255

Z.

ZYMOTIC disease, causes of, external, 1

THE END.

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