SANITARY ENGINEERING.

Daniel W. Mead.

SANITARY ENGINEERING:

A PRACTICAL MANUAL OF TOWN DRAINAGE AND SEWAGE AND REFUSE DISPOSAL.

FOR SANITARY AUTHORITIES, ENGINEERS, INSPECTORS, ARCHITECTS, CONTRACTORS, AND STUDENTS.

✓ BY

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With Numerous Illustrations.

LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED.
PHILADELPHIA: J. B. LIPPINCOTT COMPANY.
1902.

PREFACE.

THAT Sanitary Engineering is a science of great importance must by now be admitted to be an undoubted fact. It engages the attention of many of the well-known Engineers and Chemists of the present day. Universities are awarding diplomas to students showing an efficient knowledge of the subject, and Lecturers have been appointed to give special courses dealing particularly with this branch of Engineering. A Royal Commission has been appointed by the Government to study the methods employed in purifying sewage, and to report on the course of action to be taken in future as a basis for the guidance of those who have the disposal of these foul liquids in hand. Corporate bodies have also been sanctioned by Parliament, and they have sprung into existence for the specific purpose of enforcing Local Authorities to satisfactorily deal with the human, house, and trade refuse that may come within their jurisdiction.

It has quickened into active being a profession which has been gradually growing throughout a lengthy period of years. Indeed, such are the signs of its increasing importance and complexity that I fully expect before long it will have a still more recognised status at Engineering Colleges than it has at present.

Unfortunately its students have, until recently, had to depend for their sources of information and instruction on what could be gathered from a minute and careful search through numerous volumes, essays, and lectures. But even this diligence does not meet with its due reward, as such a search can only give an inappreciable and dissatisfying idea of the intricacies and vastness of the subject matter.

I have myself felt the want of a work which would in one small volume deal with the science in a comprehensive, concise, and easily intelligible form, and have, therefore, gathered together information, data, and material in such a manner that I trust will appeal to students and impress them with the great possibilities of its study. It is intended for the use of Municipal Engineers and Students, for Medical Officers of Health and Sanitary Inspectors, and the Members also of Local Authorities, and for those interested in the study of hydraulics and earth pressures. I trust that there will be many outside the ranks of those directly or professionally concerned who will find interesting information on various subjects within the pages of the present work, especially on that having reference to the design of Refuse Destructors and refuse destruction. This latter subject has been treated with special care, and competing systems have been considered without bias or partiality.

The greatest care has been exercised to construct recognised formulæ *ab initio* and in the simplest stages, only the most elementary knowledge of the different branches of mathematics being required. Tables of velocity and discharge have been purposely omitted for the reason that the work is intended as a Study of the Principles of Science, and that the addition of these would render the volume unwieldy.

Two Chapters are specially devoted to the study of Sewage Disposal, and most of the well-known systems are briefly and sufficiently described to give a fair idea of the methods of working them. A Chapter has been allotted to Bacteriolysis, which is more fully and amply discussed owing to the special importance which has been attached to it in recent years, and to the large amount of data available.

Each Chapter, while it deals with a subject or subjects which may be dependent on or a sequence of the one preceding it, is in itself practically complete.

I have commented upon many subjects in what is necessarily an original manner, the opinions and criticisms offered upon them being the outcome of the most careful and deliberate inquiry and thought. Reasons are given in all cases for the conclusions arrived at on disputed points, but the onus of accepting or declining them must in our present state of knowledge rest with the reader.

The greatest care has been exercised to ensure the accuracy of every statement taken from outside sources. These would have been more fully acknowledged had not my notes been unfortunately destroyed by fire when the MS. of the work was in its initiatory stage.

The illustrations have been prepared with the object of showing only the absolutely necessary detail; all other matter has been omitted for the sake of clearness. To those who have so willingly and kindly lent electros illustrating their appliances and structures, I tender my very best thanks. It must not be supposed that I advocate the use of any of the appliances or structures illustrated or even mentioned in this work. Many of them are merely given to illustrate certain principles or to show the progress made in recent years.

To the publishers I must also express myself indebted for valuable suggestions which have been made by them from time to time whilst the volume has been going through the press.

A serviceable index is provided, without which a work of this character can hardly be called complete.

FRANCIS WOOD.

LONDON, *November, 1901.*

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LIST OF WOODCUTS.

ERRATUM.

Page 76, description of Fig. 64 should be "Trap with large inlet and small outlet."

SANITARY ENGINEERING.

CHAPTER I.

INTRODUCTORY.

1. The author has thought for some years that a work dealing with the science of sanitary engineering in an elementary form would be very acceptable to the engineering public. It has been with this object in view that he has been collecting together material, which may be said to be the result not only of personal knowledge, but also the outcome of the experience and suggestions of others. It has been gathered into shape, and was recently given in a series of lectures to a few private engineering friends, and is now offered more especially to engineering students; at the same time, however, it is hoped that the engineer himself will find something of value in the matter set forth.

2. It is not intended to go deeply into the history of sewerage design, nor into its increasing importance in the public estimation, but rather to treat the subject from its present condition, and, if possible, suggest its future development. It must be almost needless to say that the science is in its primary stage, even though it has been usefully known for a period of, say, half a century; undoubtedly the schemes of to-day are totally different and more advanced in their principles than they were two or three decades ago, but the increasing cry of "economy" on the part of the ratepayers demands that engineers should be thoroughly grounded in the science in order to bring schemes to a satisfactory and efficient conclusion. That engineers vary in their bases and principles of design must be patent to all who have examined the systems of sewerage in various towns. There may be cause for this variation, but in some cases it is very difficult to see why it exists.

3. The suggestions which will be embodied are not new in all cases—this is mentioned advisedly—on account of the fact that, though several of them have been thought to be original, the author has been confounded by finding some of his suggestions in old essays, and that others have been actually patented many years ago

by other persons. The authors of other works are, therefore, here thanked for their information, which is otherwise not acknowledged, as it will be impossible to mention every source from which items may have been taken.

4. There are many works dealing with sanitary engineering, sewerage, and sewage disposal, and this must be taken merely as a preliminary to those volumes which treat the subjects mentioned in this work in a more comprehensive manner. The student must, therefore, consider that he knows only a small part of this vast subject when he has read and learned the contents of the present volume.

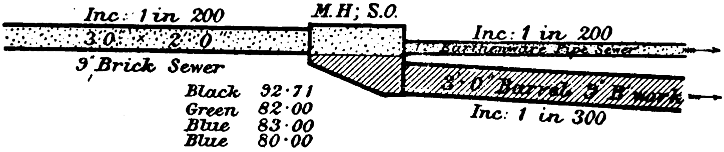
5. A small matter may be mentioned here, which is noted on account of the masses of paper that the writer has had to set out works with, so that he speaks with some feeling. In some municipal offices it is the custom to make working drawings on sheets of paper, most inconvenient in size both to resident engineer and contractor; the sections are in one long continuous roll, and are so unwieldy as to give rise to endless annoyance and irritation. Working drawings should never be on paper larger than a double-elephant sheet; this is a most useful size.

6. The ordnance sheets recently published are very convenient, and form a most useful set of engravings. A complete set of these (to the scale of $\frac{1}{500}$) should be bound in one volume, covering the whole of the drainage area of the town, and, if possible, the whole of the town itself. On these engravings the drains from each individual house may be shown; even the gas and water mains can be inserted accurately without the map being too crowded with detail. It has been the experience in many towns that the drains from the houses into the sewers are not carried out in accordance with the plans which have been approved by the local authority—this may have been through a want of inspection, or obstacles may have occurred which rendered an alteration in the line necessary. Having been so executed, no record has been kept of the same and no alteration made to the plans; consequently, when these drains are out of order, money is thrown away in trying to find them. This would be prevented if the inspectors of sewers (a necessary appointment, to act on behalf of the local council) plotted the position of the drains, when they were being laid or altered, on a "record map."

7. It is also observed here that, wherever there may be a manhole or a lamphole shown on the map, the ordnance levels of both the invert of the sewer and the surface of the ground should be given, together with the level of the invert and surface at every change of inclination; whether a manhole or lamphole be there or not, the inclination of the sewer should also be given. It will hardly be credited how useful these figures eventually become. A convenient method to adopt is to inscribe the level of the surface

in *black*, the invert of the sewer in *green*, and the invert of a storm sewer in *blue;* the size of the sewer and the inclinations, together with the line of direction of the same, will be in *green* or *blue* according as they refer to the sewer proper or to the storm culvert respectively. Fig. 1 is a sketch which now explains itself at a glance. The chamber at M.H. S.O. is a manhole and a storm overflow, the double line in green shows a sewer 3′ × 2′, egg-shaped, with an invert level of 82·00 O.D.,* the surface of the ground is 92·71 O.D., the invert of the weir of the storm overflow is 83·00 O.D., and the invert of the storm culvert is 3 feet below this. The storm sewer is 3 feet in diameter, and the foul sewer below the storm overflow is 12 inches in diameter. Any scheme mapped out on these or similar lines would prevent much confusion and be of inestimable value to all who have the drainage of any town to look after.

8. It is proposed to commence at the beginning—*i.e.*, the point where the sewage leaves the house—and then to proceed from point to point, tracing its whole course until it enters the stream or river as a purified effluent.



Note. *The sewers shown thus* ░ *would be lined and tinted in green. The sewers shown thus* ▨ *would be lined and tinted in blue.*

Fig. 1.—Sketch section of a sewer.

The student must not suppose that the mastery of the contents of books will make him a sanitary engineer; no volume will give him even a slight idea of the difficulties to be contended with in actual practice; every scheme is different from any other that has been designed, and obstacles, more or less large, occur in each, which probably have not happened before. It is here that the engineer shows himself to advantage. He must be prepared to give a solution to the difficulty, which shall be feasible, scientific, and economical.

9. To obtain a comprehensive idea of the planning and the execution of an efficient sewerage scheme, the student must have been thoroughly grounded in many subjects, a few of which are here mentioned—viz., mathematics, mechanics, hydraulics, light and heat, magnetism and electricity, chemistry, geology, building

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* Note.—The letters O.D. mean Ordnance Datum, and indicate that the figure 82·00 is 82 feet above the level of the old dock sill at Liverpool.

construction, and mechanical engineering. It is taken for granted that he can use the level and theodolite efficiently, that he can make accurate surveys, that he is a good draughtsman with power and concentrativeness sufficient to go into the minutest detail, and, lastly, that he enjoys the work and has a natural aptitude for engineering science.

10. An endeavour will now be made to point out in what direction the subjects above-mentioned may be employed in the science of sanitary engineering. (1) *Mathematics.*—Mathematics has always been the basis of everything scientific, and more especially does it apply to all engineering science; the more one knows of this subject, the easier it becomes to attack and solve problems in physics and other kindred subjects; it includes algebra, trigonometry, co-ordinate geometry, and the calculus. (2) *Mechanics* (a better term would have been *Physics*).—The study of falling bodies, inclined planes (screws, &c.), levers (wheels, &c.), balances, and friction will be of great value. "Falling bodies" suggests "falling water;" "inclined planes," "inclination of sewers;" "screws," "levers," and "balances," for all kinds of machinery; and "friction" is an all-important item in the flow of water, and in the consideration of earth-pressure, &c. (3) *Hydraulics* evidently requires the closest attention on the part of the student. (4) *Light* and *Heat.*—*Light*, to a certain extent, is very important. The sun's rays have a powerful influence on the atoms of the atmosphere; this is exemplified by the recent adoption of a method for diverting certain of them, to the exclusion of the others, into a specially prepared room in which a patient suffering from a specific disease is placed, on whom, after being subjected to this atmosphere for a time, there is a marked curative result. Also by the adoption of what is popularly known as the "sunlight treatment." Certain of the rays favour oxidisation, as also the aeration of the water subjected to their influence. *Heat* is also important, as no chemical change can take place without either the development or the loss of heat. Heat applied to sewage favours rapid decomposition; the reader, no doubt, has noticed that the smell from a sewer is more pungent in hot weather than in cold. (5) *Magnetism* and *Electricity* are subjects with which the student must have a fair knowledge. The treatment of sewage by electrolysis has been before the public for some time, and it may yet become an important factor in sewage treatment. (6) *Chemistry* is undoubtedly a study of exceeding importance to the sanitary engineer; he must be well acquainted with the principles in order to understand the composition of sewage and sewer gas; it is a well-known fact that almost every town has a different kind of sewage—*i.e.*, different in composition—and the chemicals which would be applied to the sewage of one town would have a very different effect if applied to that in another; again, a chemical

might be used which would give a very clear effluent, but this effluent, after standing for two or three days, may decompose and form offensive products—this is called secondary decomposition. Under the head of chemistry is that of bacteriology, a knowledge of which will be of invaluable assistance to the engineer in the near future. (7) *Geology.*—The engineer is a born geologist; his work is connected with the earth and its composition. The first work of the engineer is to sink trial holes in order to ascertain what the nature of the ground is, and whether or not it is suitable to the purposes for which he may require it. Being a geologist, he rapidly forms a good idea of the constructive difficulties arising from the physical features of the district, and selects the route or position that will secure the greatest safety with the least expense. He notices materials which tell him facts about which the engineer who has not studied geology knows nothing. The student must therefore take and make the most of the opportunities which he now has—and never will have again. He should study not only the subjects above-mentioned, but also all those which may pertain directly or indirectly to the furtherance of engineering projects.

CHAPTER II.

HYDRAULICS, &c.

11. MANY students and persons engaged in designing works use well-known formulæ in order to obtain the dimensions of a sewer, retaining wall, struts, ties, &c.; but, in many cases, they do not know how these formulæ have been obtained or whether they are accurate. There are scores of formulæ for the velocity of flow of water, for earth-pressures against walls, and other subjects.

All the formulæ given below have been obtained from one source for each subject, and it is the author's intention here to give the construction of several formulæ *ab initio.* It may be said, in parenthesis, that these constructions are brought forward in order that the student, knowing the source, may experiment for himself, and either confirm the symbols or else correct them so as to accord with his own conclusions. The formulæ now in use cannot all be accurate, each varying in some degree; the flow of sewage is especially a subject that has not received enough attention from this particular standpoint; again, it is possible that the student-engineer (like the author) may be, at some time or other, so situated that neither books nor formulæ are available, but, if he has fully understood the principles, he need have no fear of being able to easily form an approximately correct rule for himself.

12. It will be taken for granted that the student has passed through the elementary stages of both mathematics and mechanics, otherwise it will be impossible to follow the rapid steps used in constructing the formulæ.

Before proceeding, however, with the principle of the flow of water, two elementary terms will be specially mentioned. They should be thoroughly understood, as they are the basis of almost all subjects relating to engineering science. *Mass* and *density* are the terms to which reference will be made.

13. Two vessels, exactly the same in size, are filled with the same material, but the substance in one has been compressed; hence the quantity of the substance in the latter vessel is greater than that in the other; that is to say, the *density* of two bodies of equal volume and of the same material are proportional to their *masses*, when the term *mass* is taken as representing quantity of matter.

14. Suppose a cubic inch to represent unit volume, the unit of mass will be the quantity of matter in a cubic inch of water at

39·4° F. under a pressure of 14·75 lbs. The effect of the pressure variation is so slight that it is usually disregarded. Then the density of a body is measured by the number of units of mass in a cubic inch of its substance, and if d = density of a body whose volume is v and mass m, then

$$d = \text{the mass of a unit volume,}$$
$$m = v\,d, \text{ weight of mass } = m\,g = g\,d\,v,$$

g, as usual, representing the acceleration due to gravity in one second.

The weight of a unit mass = g units of force.

15. The numbers representing the densities of substances are the same as those which represent their specific gravities. *Specific gravity* is a measure of the weight of a substance in contradistinction to density, which is a measure of its mass. A cubic inch of water weighs about $\frac{1}{7}$ that of iron—the specific gravity of iron is therefore about 7, when the unit taken is water at its greatest density—*i.e.*, at 39·4° F, and the cubic inch is the unit volume.

In the same way the specific gravity of any other substance is measured by the weight of a unit volume of that substance.

d = mass of substance,
s = its weight,
then $s = g\,d$.

w = weight of a body whose volume is v and whose specific gravity is s. Then $w = v\,s$ or $s = \frac{w}{v}$; since $s = g\,d$, we have $w = g\,d\,v$ (see Art. 14).

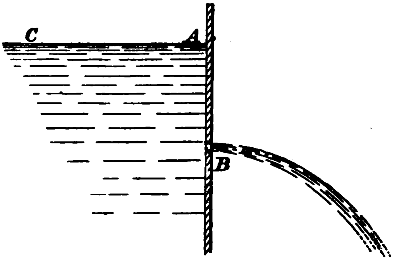


Fig. 2.—Velocity of a fluid issuing from an orifice.

16. *The velocity of issue of a liquid from an orifice in the side of a vessel is a measure of the height of the liquid above the orifice.*

Let A B represent the side of a vessel containing the liquid whose surface is A C; at B there is a very small orifice whose area = a; b represents the thickness or breadth of the particle of liquid which occupies the orifice, m represents the mass of the liquid, p = the pressure on the particle in excess of the atmospheric pressure. Then

$$p = g\,d\,a\,h, \quad h = \text{height A B.}$$

The work done by the particle is equal to the energy which the mass acquires, therefore work done = $p \times b$. But the "work done" is equal to the efficient energy which has been liberated from the mass, technically termed "kinetic energy;" the kinetic energy of a particle is $\frac{m v^2}{2}$, v = velocity of efflux;

$$\therefore p . b = \frac{m v^2}{2}, \quad \therefore g . d . a . h . b = \frac{d . a . b v^2}{2}, \quad \therefore v^2 = 2 g h.$$

It is easily seen that v can only vary when h varies; therefore the velocity of issue is due to the head of liquid above the orifice, and is a measure of the same.

17. *The path described by a particle of liquid issuing from an orifice in the side of a vessel is a parabola.*

From Statics we know that the path which a body describes when subjected to a constant uniform force will be a straight line in the direction of the force, but if the body be also acted upon by another uniform and constant force in a different direction to that of the first force, then it will move in a straight line between the directions of the forces which are being applied to the body.

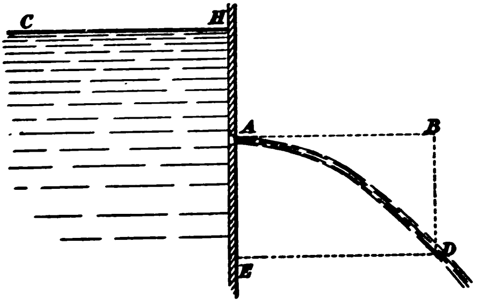


Fig. 3.—Path of a particle in a fluid jet.

In the case we are considering, the particle of liquid is being subjected to two forces, one a constant and uniform force, and the other a constantly increasing force.

In Art. 16 it was proved that the velocity of efflux of a particle from an orifice was a measure of the head. In Fig. 3, H E is the side of a vessel containing the liquid, H C is its surface, at A is a small orifice in the side of the vessel. Consider the surface H C to remain constant; then the velocity of efflux of a particle at A may be denoted by the symbol v, and this will be a constant and uniform force, its direction will be horizontal, and in any time, t, the space it will have described will be $v t$ = A B. As soon as the particle issues from the orifice, it is subjected to the action of gravity, and the space that a particle will fall under this force in a given time, t, is $\frac{1}{2} g t$ = A E. Let A E = x and A B = y. Eliminate the symbol t.

$$y^2 = v^2 t^2, \quad \therefore x = \frac{g y^2}{2 v^2}, \text{ or } y^2 = \frac{2 v^2 x}{g} = \frac{v^2}{2 g} . 4 x.$$

we know that $h = \frac{v^2}{2 g}$, $\therefore y^2 = 4 x h$.

$\therefore y^2$ bears a constant ratio to x. We know, from conic sections, that this is the equation of a parabola, its axis is vertical $=$ H E, AB is a tangent at its apex, and $\frac{v^2}{2g}$ is the distance of A from the focus of the parabola and also from the directrix, which, in this case, is the surface of the water H C.

The result here arrived at has been found to be true from actual experiments; the head does not quite coincide with the velocity, the difference being accounted for when it is considered that the resistance of the air impedes the progress of the particle, the resistance increasing as the square of the velocity, and, therefore, as the head.

18. *To obtain formulæ for the discharge over a weir and through an opening in the side of a vessel containing a liquid.*

$$\text{A E} = h', \quad \text{A G} = h, \quad \text{A F} = \text{H}.$$

In Fig. 4, let M A be the surface of the liquid and A F a barrier, and suppose E F to be an opening in the barrier having a length of one unit. Divide A F by an infinite number of ordinates equidistant from each other, and let E C, G D, and F J be three of these ordinates. The velocity of a particle at E will be $v = \sqrt{2gh'}$. In the same way, the velocity of a particle at F will be $v' = \sqrt{2g\text{H}}$, and if the velocities be plotted along each ordinate, using the same scale in every case, the parabolic curve A R C J is obtained.

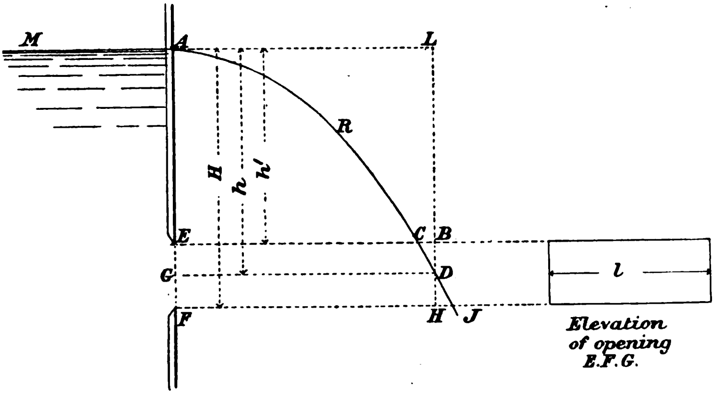


Fig. 4.—Diagram of a discharge over a weir.

From conic sections we learn that the area enclosed by A F J R A will be two-thirds the area of the rectangle on the same base F J, and of the same height A F. Now, "area" multiplied by "velocity" will give the *discharge*. It will be easily seen that the discharge in a unit of time through the opening A F will be the area of the parabolic section A F J R A multiplied by the length of the opening, which is unity.

The area of the rectangle A F H L = H . $\sqrt{2gH}$,

$\therefore$ the discharge through the opening A F whose length is l =

$$D = \tfrac{2}{3}l \sqrt{2g}\, H \sqrt{H} \ldots\ldots (1)$$

In the same way the discharge through opening AE

$$= \tfrac{2}{3} l \sqrt{2g}\, h' \sqrt{h'} \ldots\ldots (2)$$

19. The difference between (1) and (2) will give the discharge through the opening E F, whose length perpendicular to the page is l,

$$\therefore\ D = \tfrac{2}{3} l \sqrt{2g}(H \sqrt{H} - h' \sqrt{h'}) \ldots\ldots (3)$$

20. When the opening E F is small (when, in fact, it may be called an orifice), compared with the head, then the mean of the two heights h and H may be substituted—*i.e.*, the equation (3) in Art. 19 may be written, without any appreciable discrepancy,

$$D = \tfrac{2}{3} l \sqrt{2g}\, h \sqrt{h}, \text{ where } h = \frac{h' + H}{2}.$$

21. On the other hand, when the "head" is small compared with the opening, then the mean of the two heights does not apply.

Let x be the head which will give the mean velocity, then

$$AG = x, \text{ and the mean velocity } = GD = \sqrt{2gx}.$$

$$\text{The discharge, D, will be } = l \times H \sqrt{2gx} \ldots (4)$$

The discharge, as given by Art. 18, must equal that of (4),

$$\therefore\ l \times H \sqrt{2gx} = \tfrac{2}{3} l \times H \sqrt{2gH},$$

$$\therefore\ x = \tfrac{4}{9} H, \text{ and } v' = \tfrac{2}{3} \sqrt{2gH};$$

therefore the mean velocity is $\frac{2}{3}$ that of the lowest film.

22. In the same way, it may be proved that the height which gives the mean velocity in a rectangular opening is

$$y = \frac{4}{9}\left\{\frac{H\sqrt{H} - h'\sqrt{h'}}{H - h'}\right\}^2.$$

The mean velocity will be $v'' = \frac{2}{3}\sqrt{2g}\left(\frac{H\sqrt{H} - h'\sqrt{h'}}{H - h'}\right)$.

23. Owing to the sectional area of the water issuing from an opening diminishing at a certain point, the actual discharge is always less than the theoretical discharge. Michelotti and d'Aubuisson, from a large number of experiments, found that the coefficient which would allow for this contraction was 0·619. The former author gives the relative dimensions as well as the sketch

which is reproduced in Fig. 5. A B being the orifice of unit depth, then C D = 0·787 and E F = 0·498. The ratios of the areas will be as $1 : (0{\cdot}787)^2 = 1 : 0{\cdot}619$. This coefficient is generally termed the "coefficient of contraction."

In open weirs there are certain contractions which must be taken into account, viz., "end" and "side" contractions; these contractions vary, and, as an explanation would take up a considerable portion of this volume, it is intended only to give a few results and refer the reader to a standard work on hydraulics.

24. From a large number of experiments it has been found that c (a coefficient inserted in the above formulæ to make the theoretical results agree with those of actual practice) varies from 0·59 to 0·665, under certain conditions which are mentioned below.

(1) When the width of the opening is between one-third and one-fifteenth that of the channel supplying it, the coefficients vary not more than 0·591 to 0·63, the head h on the weir being between 2½ inches and 9½ inches. This gives a formula for gauging small streams:—

$$D = \tfrac{2}{3}\sqrt{2g} \times c \times l \times h\sqrt{h} = 3{\cdot}25\, l h\sqrt{h} \text{ (approximately).}$$

(2) When the width of the opening is equal to that of the channel supplying it, and the head on the sill is less than one-third the depth of the water in the channel, the coefficients remain constant at 0·665. Therefore

$$D = 3{\cdot}558\, l h\sqrt{h}.$$

(3) When, however, the width of the weir compared with that of the channel increases from 0·3 to the full width of the channel, the coefficient (0·6 for one-third the width) increases almost exactly as the excess. From experiments by Castel for every one-tenth the width in excess of three-tenths, the coefficients were increased by 0·009—*e.g.*, the formula for the discharge over a weir which was 0·3 of the total width of the channel was found to be [see (1)]—

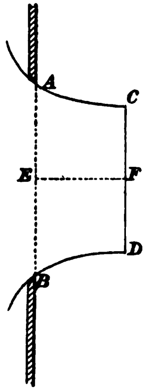


Fig. 5.

$$D = 5{\cdot}35 \times 0{\cdot}6\, l h\sqrt{h}.$$

The formula for the discharge over a weir 0·7 of the width of the supplying channel would be—

$$\begin{aligned} D &= [\{(7 - 3)\, 0{\cdot}009\} + 0{\cdot}60]\, 5{\cdot}35\, l h\sqrt{h} \\ &= 3{\cdot}35\, l h\sqrt{h}. \end{aligned}$$

25. On sewage disposal works, tanks are constructed which are so designed that one of the sides is made to act as a weir, the edge of this weir is generally at least 9 inches broad, and increases in many cases to 18 inches; the edges are also bullnosed. The for-

mulæ mentioned above would not agree with the discharge over such a weir, as the conditions for the formulæ in Art. 24 require that the sides should have knife edges. The discharge in the case of weirs where the edge of the weir is broad will be decreased, owing to the resistance from friction of this broad surface retarding the flow.

26. The discharge from a circular orifice may be obtained from the preceding articles as D = (area of orifice) × 0·619 × $\sqrt{2\,g\,h}$.

Let A = area of orifice. Then, A = d^2 × ·7854.

$$\therefore \text{D} = d^2 \times {\cdot}7854 \times \sqrt{2\,g} \times 0{\cdot}619 \times \sqrt{h} = 3{\cdot}9\, d^2 \sqrt{h}.$$

d being in feet.

D will be the discharge in cubic feet per second.

27. If an adjutage or short tube be fixed to the orifice, a considerable increase in the discharge is obtained, the cause of this increase, as explained by d'Aubuisson, is the attraction of the sides of the tube, the liquid being acted upon in much the same manner as is the case with the action of a liquid in a capillary tube. From a large number of experiments, it has been found that the coefficient increases from 0·62 for orifices to 0·82 for the flow through an adjutage.

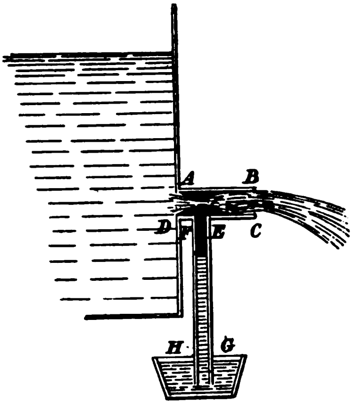


Fig. 6.—Vena contracta.

28. In Art. 23, it was explained that the sectional area of a mass of water flowing through an orifice diminished to a certain point, and it is a curious fact that a similar diminution of sectional area is found to occur when a short tube is attached to the orifice. In Fig. 6, A D is the side of a vessel in which A D is an orifice which is lengthened by means of the tube A B C D. Now, if a glass tube be inserted in the adjutage, as shown in the figure by F E G H, being hermetically jointed at the junction of the two tubes, and the lower end of the glass tube dip into a vessel containing mercury, it will be found that, when the body of water is allowed to run through the adjutage, the water absorbs the air in the glass tube and the adjutage itself until a partial vacuum is formed, and the mercury will rise in the glass tube to a height nearly equal to the head of water above the orifice.

29. Mention has been made in the previous articles of rectangular notches in weirs, and of circular and rectangular orifices; there is still another form which it is well that the student should be

acquainted with, viz.:—The triangular notch, which presents an important fact not met with in the rectangular form. Whatever the head on the apex may be, the section of the flow of the water is similar in every case; consequently the coefficient of discharge is practically constant. This does not apply to the comparison of a very large surface at the top to a surface of that of a very small quantity, but in the main it does apply.

30. To obtain a formula for these openings it is much easier to use the integral calculus. The flow of the water from any orifice is a parabola in side elevation, but the front elevation may be of any section—*i.e.*, rectangular, trapezoidal, triangular, circular, &c. In the rectangular opening the infinitely small areas are equal to each other, while the head alone increases. In the trapezoidal, triangular, and circular openings, the elementary areas vary in area with every increase of height. The volumes of such figures will be found as follows:—

31. **Rectangular Opening.**—Using the same symbols as in Art. 19,

$$(a) \qquad D = c\sqrt{2gl}\int_{h'}^{H} h^{\frac{1}{2}} = \frac{2}{3}c\sqrt{2gl}\,(H\sqrt{H} - h'\sqrt{h'}).$$

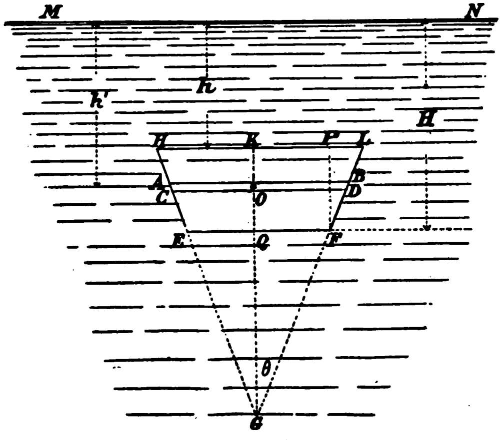


Fig. 7.—Trapezoidal opening.

32. **Trapezoidal Opening.**—Let M N be the surface of the water, and H L E F the trapezoidal opening through which the water is to pass.

Take a small strip A B C D, and find its area. Let h be the depth from the surface to the centre of the strip. Let Δh be the depth of the strip and H K = K L.

$$\text{Then the area} = \Delta h \times 2\,OG \tan\theta.$$

$$\text{Tan}\,\theta = \frac{PL}{PF} = \left\{\frac{l_t - l_b}{2}\right\}\frac{1}{d}$$

$$\mathrm{KG : KL :: QG : QF} = d + \mathrm{QG : KL :: QG : QF}$$

$$\therefore\quad d\,.\,\mathrm{QF} + \mathrm{QF\,.\,QG} = \mathrm{KL\,.\,QG}$$

$$\therefore\quad d\,.\,\mathrm{QF} = \mathrm{QG(KL - QF)}, \text{ and } \frac{d\,l_b}{2} = \mathrm{QG}\left(\frac{l_t - l_b}{2}\right)$$

$$\therefore\quad \frac{d\,l_b}{l_t - l_b} = \mathrm{QG}.$$

$$\mathrm{OG} = \mathrm{OQ} + \mathrm{QG} = \mathrm{H} - h' + \mathrm{QG}$$

$$= \mathrm{H} - h' + \frac{d\,l_b}{l_t - l_b}$$

The area of the strip $\therefore = \Delta h\,2\left(\mathrm{H} - h' + \dfrac{d\,l_b}{l_t - l_b}\right)\left(\dfrac{l_t - l_b}{2}\right)\dfrac{1}{d}$

$$= \Delta h\left\{(\mathrm{H} - h')\left(\frac{l_t - l_b}{d}\right) + l_b\right\}$$

$$\mathrm{D} = \text{Discharge} = \sqrt{2g}\int_h^{\mathrm{H}} h'^{\frac{1}{2}}\left\{l_b + (\mathrm{H} - h')\left(\frac{l_t - l_b}{d}\right)\right\}\Delta h$$

$$= \sqrt{2g}\int_h^{\mathrm{H}}\left\{l_b\,h'^{\frac{1}{2}} + (\mathrm{H}\,h'^{\frac{1}{2}} - h'^{\frac{3}{2}})\left(\frac{l_t - l_b}{d}\right)\right\}\Delta h$$

$$= \sqrt{2g}\left\{\tfrac{2}{3}\,l_b\,(\mathrm{H}^{\frac{3}{2}} - h^{\frac{3}{2}}) + \tfrac{2}{3}\mathrm{H}\,(\mathrm{H}^{\frac{3}{2}} - h^{\frac{3}{2}})\frac{l_t - l_b}{d} - \right.$$

$$\left.\tfrac{2}{5}\,(\mathrm{H}^{\frac{5}{2}} - h^{\frac{5}{2}})\,\frac{l_t - l_b}{d}\right\}$$

$$(b)\qquad \mathrm{D} = \tfrac{2}{3}\,c\,\sqrt{2g}\left\{(l_b\,\mathrm{H}^{\frac{3}{2}} - l_t\,h^{\frac{3}{2}}) + \tfrac{2}{5}\,(l_t - l_b)\,\frac{\mathrm{H}^{\frac{5}{2}} - h^{\frac{5}{2}}}{d}\right\}$$

33. **Triangular Opening.**—l_b for a triangular opening will = 0. Eliminate l_b from equation (*b*), Art. 32, and we have—

$$(c)\qquad \mathrm{D} = \tfrac{2}{3}\,c\,\sqrt{2g}\left\{\tfrac{2}{5}\,l_t\left(\frac{\mathrm{H}^{\frac{5}{2}} - h^{\frac{5}{2}}}{d}\right) - l_t\,h^{\frac{3}{2}}\right\}.$$

If H K = K L, then $\dfrac{2\,\mathrm{KL}}{\mathrm{H} - h} = 2\tan\theta = \dfrac{l_t}{d}.$

$$(d)\qquad \text{Then } \mathrm{D} = \tfrac{4}{3}\,c\,\sqrt{2g}\tan\theta\left\{\tfrac{2}{5}\,(\mathrm{H}^{\frac{5}{2}} - h^{\frac{5}{2}}) - h^{\frac{3}{2}}\,d\right\}.$$

e.g., If $\theta = 45°$—*i.e.*, the opening is a right-angled triangle, and $h = 0$.

$$\text{Then } \mathrm{D} = \tfrac{8}{15}\,c\,\sqrt{2g}\,\mathrm{H}^{\frac{5}{2}}.$$

c is the coefficient of discharge formed by experiment, see Arts. 23 and 24.

With an orifice of this type even the smallest quantity of water flowing is measurable; the space in times of flood increases as the quantity to be measured increases, and admits here the measurement quite as accurately as for a small flow.

34. **Circular Opening.**—Let r = radius of the circular opening, H E the surface of the water, A C R D F B the circular opening. Let H O = h, and the angle C O R = θ. Area of strip A B R D = $2\ r^2 \sin^2 \theta \ \Delta\ \theta$. Centre of gravity of strip = $h - r \cos \theta$.

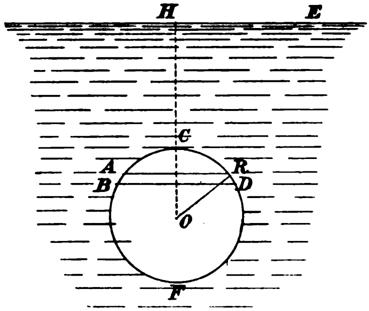


Fig. 8.—Circular opening.

$\therefore$ D = $\int \sqrt{2\,g\,k}$. area. k representing the depth of the centre of gravity.

$$\therefore \ D = \int_0^\pi \sqrt{2\,g}\ \sqrt{h - r \cos \theta} \times 2\,r^2 \sin^2 \theta \,\Delta\, \theta$$

$$= \int_0^\pi \sqrt{2\,g}\,h^{\frac{1}{2}} \left(1 - \frac{r}{h} \cos \theta\right)^{\frac{1}{2}} .\ 2\,r^2 \sin^2 \theta \,\Delta\, \theta.$$

$$(e)\ D = c\,r^2\,\pi\ \sqrt{2\,g\,h} \left(1 - \frac{r^2}{32\,h^2} - \frac{15}{192}\,\frac{r^4}{h^4} - \&c.\right).$$

35. From (b) in Art. 32, suppose H L coincides with M N—

$$\text{Then D} = \frac{2\,c}{3}\ \sqrt{2\,g}\ \left\{ l_b\,d^{\frac{3}{2}} + \tfrac{2}{5}\,(l_t - l_b)\,\frac{d^{\frac{5}{2}}}{d} \right\}$$

$$= \frac{2\,c}{3}\ \sqrt{2\,g}\ \{l_b\,d^{\frac{3}{2}} + \tfrac{2}{5}\,l_t\,d^{\frac{3}{2}} - l_b\,d^{\frac{3}{2}}\}$$

$$= \frac{4\,c}{15}\ \sqrt{2\,g}\,l_t\,d^{\frac{3}{2}}.$$

36. And in the case of the triangular notch the result will be—

$$D = \frac{8}{15}\,c \tan \theta\ \sqrt{2\,g}\ d^{\frac{5}{2}},$$

$$\text{or D} = \frac{4}{15}\,c\ \sqrt{2\,g}\,l_t\,d^{\frac{3}{2}}.$$

37. Similarly the student will be able to work out other results

—*e.g.*, from (*b*); by substituting l for l_t and l_b, we get a rectangular notch, and

$$D = \tfrac{2}{3} c \sqrt{2g}\, l \left\{H^{\frac{3}{2}} - h^{\frac{3}{2}}\right\}, \text{ see } (a) \text{ in Art. 31.}$$

38. When measuring the head of water on the sill of a weir, care must be taken to take the level of the surface at some distance from the weir itself—*i.e.*, at a point where the curvature is *nil*. In Fig. 9, A C is the opening of a weir, D A represents the surface of the still water in the channel, the head on the sill is then A C; for it has been found that the velocity of the water at the point B is just equal to the velocity that a particle would obtain by falling through a space A B.

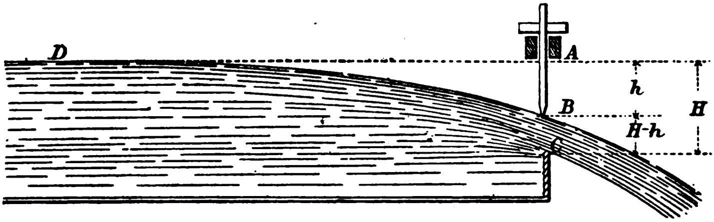


Fig. 9.—Flow through a rectangular notch.

The volume of water in the channel must also not have a velocity of approach, otherwise this velocity must be considered in calculating the discharge.

39. In any gauging that may have to be carried out in the designing of a sewerage scheme, care should be taken to ensure (for the sake of accuracy) that the sectional areas, widths of weirs, &c., agree with, or are similar to, those on which the formula (to be taken as a means of calculating the discharge) has been based, or *vice versâ*.

It will be advisable to note that if the sectional area of the volume of water flowing over the weir exceeds one-fifth that of the supplying channel, then the initial velocity or velocity of approach is appreciable, and must be allowed for in the calculation of the discharge.

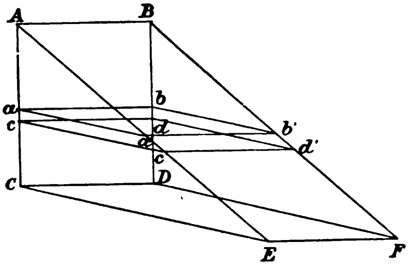


Fig. 10.—Fluid pressure on a plane area.

40. To find the *fluid pressure on a plane area*—*e.g.*, a wall.

The pressure of a liquid on a plane surface is proportional to the depth of the plane below the surface.

Let A B C D (Fig. 10) be the plane area, with the side A B in the surface of the liquid, and the area vertical. Draw D F perpendicular to B D and normal to the plane A D. Make D F equal to B D. Complete parallelogram C D E F, and join A E and B F. Now, suppose the plane A D to be divided into an innumerable number of strips parallel to A B, and let $a\,b\,c\,d$ be one of these strips; complete the parallelograms $a\,b\,b'\,a'$ and $c\,d\,d'\,c'$. Then the pressure on the strip $a\,b\,c\,d$ =

$$p = w \times \text{area } abcd \times \mathrm{B}b.$$

w being the weight of a unit volume of the liquid.

$$\begin{aligned} \therefore\ p &= w \times abcd \times bb' \\ &= w \times \text{volume of slice } abb'a'cdd'c'. \end{aligned}$$

$$\therefore \text{ Total pressure P} = w \times \text{volume of wedge ABCDEF.}$$

The centre of pressure of this volume will be at the centre of gravity of the wedge which is at a height $\frac{\mathrm{BD}}{3}$ from the bottom.

41. From the above we obtain the pressure of water against a vertical wall. Suppose E A C (Fig. 11) to be the surface of the water, and A B the vertical face of the wall, then from the above we obtain the moment tending to overturn the wall about the point B. Let A B = height h; w = weight of unit volume of water.

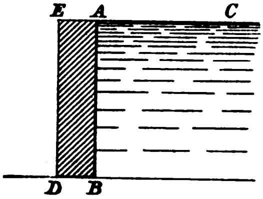


Fig. 11.—Pressure of water against a wall.

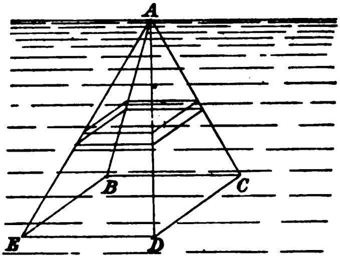


Fig. 12.—Pressure against a triangular plane.

$$\text{Total pressure} = w \times \text{volume of wedge ABCDEF}$$

$$= \frac{w \times h^2 \times l}{2} \qquad l = \text{length of wall} = 1 \text{ foot.}$$

$$\text{Moment} = \frac{w \times h^2 \times l \times h}{6}$$

$$= \frac{w h^3 l}{6} = \frac{w h^3}{6}.$$

42. In a similar manner we may obtain pressures against any surface—*e.g.*, suppose the plane to be a triangle—(1) the apex A in the surface of the liquid and the plane A B C vertical. Take the pressure on a small strip, graphically constructed as in Art. 40; then the total pressure will similarly be found to be the weight of the triangular prism A B C D E (which may be termed the pressure prism), and the weight will act at a point three-fourths of the depth below the surface—*i.e.*, through the centre of gravity of the prism. It must be remembered in this example the length C D (Fig. 12) is not equal to A C, but to the depth of the base B C below the surface, B C being horizontal. (2) Suppose in the second case that the base is in the surface and the plane vertical. The pressure on the strip is equal to the volume of the slice, and consequently we obtain the total pressure as the volume of the pyramidal prism D A B C. The centre of gravity of this prism is at half the depth below the surface, and the weight will act at half the height of E C (Fig. 13) below the surface.

43. *Example.*—Required the magnitude and position of the resultant pressure on a flood gate, the level of the water being different on the two sides.

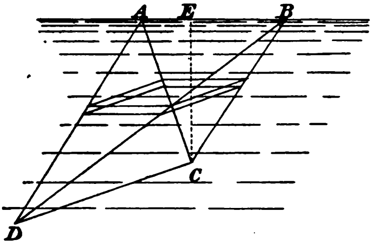


Fig. 13.—Pressure against a triangular plane.

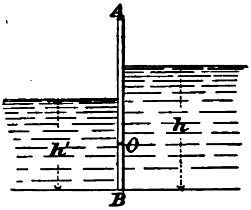


Fig. 14.—Pressure on a gate.

Let A B be the gate and b the width of its opening, h and h' the heights of the water on each side of the gate respectively.

$$\text{Total pressure on one side} = h\,b \times \frac{h}{2} \times w = P = \frac{h^2\,b\,w}{2}.$$

$$\text{,, \quad ,, \quad other ,,} = h'b \times \frac{h'}{2} \times w = Q = \frac{h'^2\,b\,w}{2}.$$

$$P \text{ acts at } \frac{h}{3} \text{ and } Q \text{ acts at } \frac{h'}{3}.$$

$$\text{Resultant} = P - Q = (h^2 - h'^2)\,\frac{b\,w}{2}.$$

The resultant acts at the point O, and its position may easily be determined by applying the method of finding the position of the resultant of two parallel and opposite forces; thus

$$(h^2 - h'^2)\frac{b\,w}{2} \times x = \frac{h^2\,b\,w}{2} \times \frac{h}{3} - \frac{h'^2\,b\,w}{2} \times \frac{h'}{3} = \frac{b\,w}{2}\left(\frac{h^3 - h'^3}{3}\right),$$

$$\therefore \; x = \frac{1}{3}\left(\frac{h^3 - h'^3}{h^2 - h'^2}\right).$$

44. By a similar application, the position of the hinge in a flushing gate which tips over when the water reaches a certain height may be found. These gates are commonly known as automatic flushing gates. The gates are not, as a rule, rectangular in shape; generally they are semicircular or egg-shaped; the centre of pressure, however, will be found by determining the centre of gravity of the pressure prism, which will vary as the area of the gate varies.

45. **Leap Weirs.**—These weirs are used as storm overflows in a sewerage system; further details will be given when treating the subject of storm overflows (Art. 247).

The ordinary dry-weather flow of water, when passing down a sewer or channel across which is placed a leap weir, as shown in Fig. 15, will flow into the chamber A B C, through the sewer A C B, and on to the sewerage works to be purified.

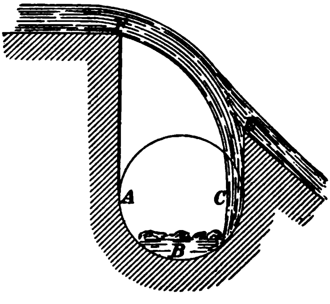


Fig. 15.—Leap weir.

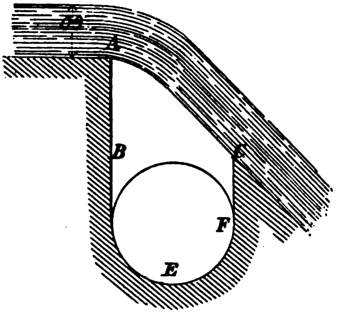


Fig. 16.—Automatic overflow.

When, however, the water acquires a greater velocity, it indicates that something more than dry-weather flow is coming down the sewer; it is then that the water leaps the space F E, flows over the lip E, and finds its way to the river or stream.

46. Although sewers are usually circular or egg-shaped, in the calculations about to be made it will be taken that the channel is rectangular.

The known quantities would be the volume of sewage or water flowing down the channel which is to completely pass over the lip

E, or the volume which is to completely pass into the chamber A B C, together with the inclination and dimensions of the channel; from these the velocity of the water at the point F and the depth at this point will readily be obtained.

The mean height h (see Art. 21) will then be $\frac{4}{9}$ the depth H of the water, together with the height h', which will represent the head of water necessary to obtain the velocity at the lip F—

$$i.e., \ h = \tfrac{4}{9}(\mathrm{H} + h').$$

Let the width of the opening A C = y, and the height vertically of F above E = x.

We know (Art. 17) that the water passing over F will flow in the form of a parabola,

$$\therefore \ y^2 = 4xh.$$

The mean velocity (Art. 21) will be $\frac{2}{3}$ that of the lowest film therefore the mean velocity

$$v = \tfrac{2}{3}\sqrt{2g(\mathrm{H} + h')} = \tfrac{2}{3} \times 8{\cdot}024\sqrt{\mathrm{H} + h'} = 5{\cdot}35\sqrt{\mathrm{H} + h'}.$$

47. Take a simple case and let (H + h') = 0·9 foot. Let x = A B and y = B C in Fig. 16. Arbitrarily fix either x or y as 1 foot. Let x = 1 foot, to find y.

$$\begin{aligned} y^2 &= 4xh, \\ \text{but } h &= \tfrac{4}{9}(\mathrm{H} + h'); \\ \text{then } h &= 0{\cdot}4213 \text{ foot}, \\ \therefore \ y^2 &= 4 \times 1 \times 0{\cdot}4213. \\ y &= 1{\cdot}3 \text{ feet nearly.} \end{aligned}$$

From these figures we find that, with a head of 11 inches in the channel, the water completely leaps the space A C and flows down C D when A B = 1 foot and B C = 1·3 feet.

48. To find the depth of water on the invert of the channel which will flow completely into the chamber.

Let $\mathrm{H} = (1{\cdot}3 - h)$, where $h + \mathrm{H} = y$ and $\frac{4}{9}\mathrm{H} = \frac{h^2}{4}$. Substitute and we have

$$\frac{4}{9}(1{\cdot}3 - h) = \frac{h^2}{4},$$

$$\frac{5{\cdot}2}{9} - \frac{4}{9}h = \frac{h^2}{4},$$

$$9h^2 + 16h - 20{\cdot}8 = 0,$$ a quadratic equation which, by solving, gives $h = 0{\cdot}87$;

$$\therefore \ \mathrm{H} = y - h = 1{\cdot}3 - 0{\cdot}87 = 0{\cdot}43 \text{ foot.}$$

When the water on the invert is 0·43 feet deep, or about 5 inches, it enters the chamber completely; between the depths 11 inches and 5 inches the water will partly go into the chamber and partly over the lip C and down C D.

49. Suppose the channel or sewer discharges at a given rate in gallons or cubic feet per minute, the student must then find what

head there ought to be at the lip A, either from experiment or from one of the formulæ given in Chapter III.

Having fixed the velocity in v feet per second, in t seconds the space passed over by a particle will be $v\,t$ feet, and in the same time it will have dropped, by the action of gravity, through the space $\frac{1}{2}\,g\,t^2$, the action of gravity does not alter its position horizontally, but does so vertically (see Fig. 18).

50. It is possible, in a rough way, to find the discharge of streams of water by taking measurements of the curve which is made by the falling water. The author used this method when the discharges of a number of pipes into a river were required; the results were very satisfactory, very quickly obtained, and eventually were found to be a very near approximation.

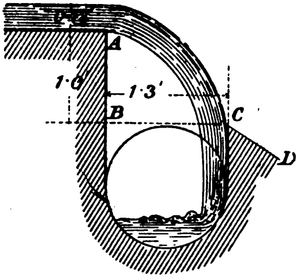


Fig. 17.—Automatic inflow.

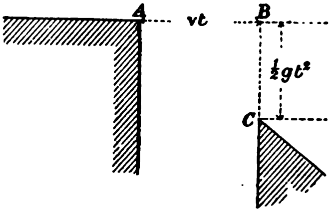


Fig. 18.—Head for determining rate of flow.

51. **Principle of a Syphon.**—In Fig. 19, B A D is a bent hollow tube open at both ends, having one arm A D longer than the other A B. Block the end A B temporarily, invert the pipe from the position shown, and fill the whole of the tube with water; stop the end D with a stopper, and place the end B in a tank of water, and the other in the air outside at a lower level. Take the stopper from D, and very little, if any, water will issue; remove the stopper from B, and water will at once begin to flow, and will not stop until the water in the tank has sunk to the level B.

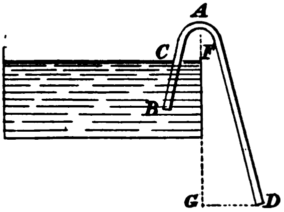


Fig. 19.—Principle of a syphon.

To investigate the action of the syphon, let X = the height of the column of water that would represent the atmospheric pressure per unit of area on the surface of the water.

Consider the pressures on each side of a unit area in the section of the tube at the point A when there is liquid in both parts A B and A D. Then the pressure on this area from the tank side will be the same as the pressure on the surface lessened by the pressure due to the weight of water in the arm B A, which will therefore = X - A F; similarly, the pressure on the other side will be X - A G. As A G is greater than A F, and X is constant, the resultant pressure will be in the direction of D A and equal to the difference in height of A G - A F = F G. There will, therefore, be a flow in the tube which will discharge at D until the surface of the water F C reaches the inlet B. It is evident that the surface of the water cannot in any case be lower than D, and the length of the arm from the surface of the water to the point A cannot also be greater than the height X.

The velocity from the opening D will be $v = \sqrt{2gh}$ where h = the height F G.

It will be seen that the syphon will not act if a hole is drilled in the tube between A and C.

CHAPTER III.

FORMULÆ FOR VELOCITY OF WATER IN PIPES, &c.

52. GRAVITY is practically the sole force which causes a mass of water to have motion in a bed of any form. Suppose the inclination of the bed to have an angle $= \theta$. The measure of the force of gravity $= g \sin \theta$, g being the acceleration due to gravity.

Suppose the inclination to be 12 feet to the mile, then

$$g \sin \theta = \frac{32 \cdot 2}{440} = \cdot 07316 \text{ foot per second.}$$

We know that a body falling through space increases in velocity at the rate of 32 feet at the end of every second. At the end of the 1st second it has a velocity of 32 feet per second, at the end of the 2nd second the velocity is increased to 64 feet per second, and so on. If, then, the water flowing in a channel or pipe met with no resistance, it would descend with ever-increasing velocity. But experiments have shown that after a few seconds the velocity becomes uniform for equal spaces along its course. There must, therefore, be a force which after a certain time just overcomes the action of gravity; the only retarding force is the resistance which the contact surfaces offer to the flow. This force is called "Friction."

53. **Friction.**—Du Buat found that (1) friction is independent of the pressure—*i.e.*, if water in a pipe has a head of, say, 100 feet, the effect of friction is the same as in a pipe having a head of 1 foot.

(2) The resistance, the velocity being the same, is proportional to the surface which may be in contact with the water. Darcy and Bazin, two French engineers, found that the resistance arising from the surface, was disseminated among all particles of the water, but that those which were nearest the surfaces in contact with the water were more affected than those in the general body of the water.

54. Fig. 20 is a sketch of the channel which was used in the experiment. The lines 1, 2, 3, 4, 5, and 6 are contours of equal velocity. The greatest velocity was found to be at A, about $\frac{1}{3}$ the depth from the surface; the contour (3) was the mean velocity in the channel. These contours explain the assumption already made, the velocities 4, 5, and 6 being very much nearer to

the surfaces in contact and to each other than the three other velocities 1, 2, and 3.

The conclusion that they and other hydraulicians have come to is that the resistance is directly proportional to the surface and inversely as the volume. The surface which is exposed to the current of water is generally termed the "wetted perimeter"; we have, then, taking the length as unity,

$$\text{The resistance} = \frac{\text{wetted perimeter}}{\text{area of section of water}} = \frac{\text{length ABCDEF}}{\text{area ABCDEFA}} = \frac{\text{L}}{\text{A}} = \frac{1}{\text{R}}$$

where L = wetted perimeter, and A = area of the section of the water.

(3) The resistance also increases as the square of the velocity nearly, the wetted perimeter being constant. By Coulomb's experiments it was found to approximate very closely to $a\,v + b\,v^2$ where a and b are to be deduced from experiments. Prony, a French engineer, founded his formula on this principle.

(4) The resistance is proportional to the density of the liquid.

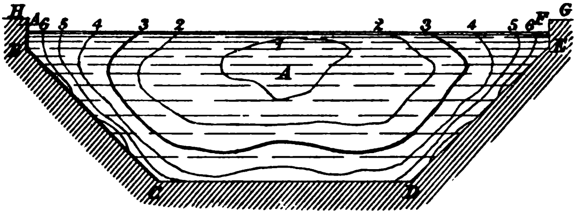


Fig. 20.—Rate of flow in a channel.

55. It may be gathered from the first and second laws of resistance to the flow of water, and from the third law (not taking into consideration the value $a\,v$ in $a\,v + b\,v^2$, which is very small for rivers and mean velocities over 3 feet per second) that

$$\text{Resistance} = \frac{\text{L}}{\text{A}}\,b\,v^2,$$

i.e, we may thus sum up the forces which just overcome the action of gravity; therefore

$$g\frac{h}{l} = \frac{\text{L}}{\text{A}}\,b\,v^2,$$

$\frac{h}{l}$ being the sine of the inclination of the surface of the river or channel, all measured in feet and seconds.

Substitute for $\frac{h}{l}$ and $\frac{\text{A}}{\text{L}}$ the letters S and R respectively, then

$$\frac{b}{g}\,v^2 = \text{R S},$$

g being a constant quantity, substitute C for $\frac{g}{b}$, and we have the very familiar looking formula,

$$v = C\sqrt{RS}.$$

56. C is to be determined by experiment, and is dependent on the roughness or smoothness of the surface of the channel or pipe. C varies more nearly with the hydraulic mean depth (area divided by the wetted perimeter = R) than with the velocity v. Bazin found that it increased with an increase of slope, but the coefficients he used decreased with the increase of slope. He was of opinion that this was not of such importance as to be taken into account in the above formula.

$$\frac{b}{g}v^2 = RS.$$

He substituted for $\frac{b}{g}$ the coefficient $\left(\alpha + \frac{\beta}{\sqrt{R}}\right)$, and then, from experiments, he found certain values for both coefficients.

	Channel.	α.	β.
I.	Cement, Carefully planed wood,	0·000046	0·0000045
II.	Smooth ashlar, Brick, Unplaned wood,	0·000058	0·0000133
III.	Rubble masonry,	0·000073	0·00006
IV.	Earth,	0·000085	0·00035
V.	Carrying detritus and coarse gravel,	0·000122	0·0007

57. Ganguillet and Kutter* in explaining the formula,

$$v = c\sqrt{RS},$$

say that c varies (1) with the degree of roughness of the wetted perimeter, decreasing with the increase of roughness; (2) with the value of the mean radius R, increasing with its increase; (3) with the slope, decreasing with its increase in large streams, and increasing with its increase in small streams.

Bazin's formula (Art. 56) contains the first and second of these conditions, and only partially embraces the variations which appear from the result of experiments, thus rendering the formula useful only under certain conditions.

Kütter, in forming a general or universal formula, first took Bazin's for his base and made $\frac{1}{\alpha} = y$, and $\frac{\beta}{\alpha} = x$, obtaining thereby

$$c = \sqrt{\frac{y}{1+\frac{x}{R}}}.$$

---

* For tables, diagrams, and other information, see Ganguillet and Kutter's *Flow of Water in Rivers and Channels*, translated by R. Hering and J. C. Trautwine, New York.

He then amended the form to $c = \dfrac{y}{1 + \dfrac{x}{\sqrt{\text{R}}}}$, and found this to give the value of c as correctly as that of Bazin.

He, after further trials, found that y could not have a constant value, but that it must vary with x, and the best result for the value of y was $a + \dfrac{l}{n}$ and $x = an$, the next stage of the value of

$$c = \frac{a + \dfrac{l}{n}}{1 + \dfrac{an}{\sqrt{\text{R}}}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

a and l being constants, and n being the only variable.

So far the variation of the slope is neglected; to bring this into the formula he assumed for y an expression of the form

$$y = y_1 + \frac{m}{\text{S}},$$

in which $y_1 = a + \dfrac{l}{n}$ and m is a coefficient constant in value, thus—

$$y = a + \frac{l}{n} + \frac{m}{\text{S}},$$

and as $x = an = ny - l$, See (1.)

$$x = \left(a + \frac{m}{\text{S}}\right)n.$$

We thus have his general value for

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

The values of the constants are given :—

English Measure.	Metric System.
$a = 41{\cdot}66$, ...	23
$l = 1{\cdot}81132$, ...	1
$m = 0{\cdot}0028275$, ...	0·00155.

Channel.	n.
I. Carefully planed boards, ...	0·010.
II. Common boards, unplaned, ...	0·012.
III. Ashlar, neatly jointed brickwork, ...	0·013.
IV. Rubble masonry, ...	0·017.
V. Earth, ...	0·025.
VI. Detritus and aquatic plants, ...	0·030.

Sewage flowing down a brick conduit n varies from 0·0138 to 0·0199.

58. In Vol. cxxii. of the *Minutes of the Institution of Civil Engineers,* Messrs. Crimp and Bruges set out certain claims for the formula

$$v = 124 \sqrt{R^2} \sqrt{S};$$

this is not in substitution for the formula of Ganguillet and Kutter, but for all sizes of channels of good brickwork or of cast iron.

This formula gives a close approximation to Kutter's formula when n lies between about 0·012 and 0·013.

Their experiments were conducted in two sewers, one in new brickwork, very smooth, and the other was of smooth brickwork, with the bottom courses slightly eroded after being in use twenty-eight years. The value of n in each case was = 0·0095 and 0·0122 respectively.

This formula must not be understood to be an universal or general formula, but as it approaches so closely to Kutter's for the cases given, it is advantageous to possess such a simple one, which can be employed without reference to tables or diagrams. If tables or diagrams are to be used, then Kutter's is just as easy to follow as the simple one here proposed.

59. It will be noticed, in the two cases experimented with, that the brickwork is smooth or slightly eroded; it will also be observed that at the end of Art. 57 the value of n for sewers is given as varying from 0·0138 to 0·0199. These are the values set down by Ganguillet and Kutter for the Dorchester Bay Tunnel, where the brickwork was hard, well pointed, covered with sewage slime; it was not known whether there was any deposit, and the flow was of sewage or sewage and sea water.

In sewerage works, one has to deal with old sewers, brickwork covered with sewage slime, and not with new sewers, but with sewers that will have to be in existence for twenty and thirty years; also there must be taken into consideration a number of disturbing influences, such as branch connections from houses, gullies, &c. These may impede or accelerate the flow.

60. Other well-known formulæ are given:—

Neville's, . $v = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$ feet per second.

Beardmore, . $Q = 2356 \dfrac{\sqrt{d^5}}{\sqrt{\dfrac{l}{n}}}$ cubic feet per second.

Weisbach, . $v = \dfrac{\sqrt{2gh}}{\sqrt{1 + e + c\dfrac{l}{d}}}$.

$e = 0{\cdot}505$, $c = 0{\cdot}01439 + \dfrac{0{\cdot}016921}{\sqrt{v}}$, d = diameter in feet, l = length, h = head or fall in feet for the length l.

61. In dealing with the velocity of water in channels allowance must be made for quick bends and curves, as they have considerable resistance to the flow; there are several retarding influences, the flow depending on the (1) radius of the curve; (2) the angle between the directions of the flow; (3) the radius of the pipes; (4) the velocity of the water; and (5) the loss due to eddies.

Weisbach's formula for bends in circular pipes is:—

$$\left.\begin{matrix}\text{Head lost on account of the}\\ \text{friction in bends, . .}\end{matrix}\right\} = \frac{\theta}{\pi}\left\{0{\cdot}131 + 1{\cdot}847\left(\frac{d}{2r}\right)^{\frac{7}{2}}\right\}\frac{v^2}{2g},$$

Where θ = angle through which it is bent.
π = 2 right angles.
r = radius of curvature in inches.
d = diameter of pipes ,,
v = velocity in feet per second.

62. **To find the Hydraulic Inclination.**—The expression known as the hydraulic mean depth is obtained by dividing the area of the cross-section of the pipe or channel by the wetted surface or perimeter, and is equal to R (Art. 54). This is mentioned here to show the difference between hydraulic mean depth and hydraulic inclination about to be explained.

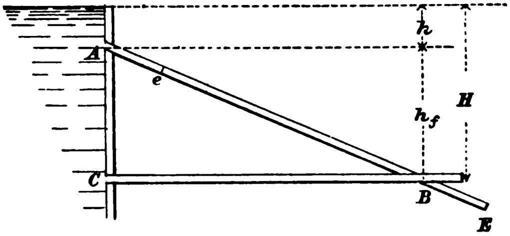


Fig. 21.—Hydraulic inclination.

Suppose c_f = coefficient for head due to the resistance of friction.
h = head necessary to overcome (1) the friction of the entrance into the orifice of the pipe, and (2) to give the required velocity v in feet per second.
l = length in feet.
h_f = head due to the resistance of friction of water flowing in a pipe of length l.
Then $h + h_f$ will be the total head H.

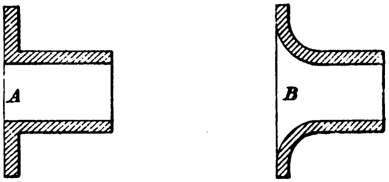
In Fig. 21 let A B be a given length of pipe and C D a length equal to A B but horizontal. Let the depth from the surface of the water to A ($= h$) represent the head due to the velocity in pipe C B, then the discharge from the end of the pipe C B will be equal to that from the pipe A B at B, and it will also be the same as if the pipe A B were cut off at e or lengthened to E.

A C will equal h_f, and $\frac{h_f}{l}$ will represent the hydraulic inclination.

Neville says, "When the height h is very small compared with the head h_f due to friction or to the whole height H, as it is in very long tubes with moderate heads, $\frac{H}{l}$ may be substituted for $\frac{h_f}{l}$ without error; but for short pipes up to 1000 diameters in length the latter only should be used in applying Du Buat's and some formulæ, which only allow for the head due to friction."

63. Neville gives the coefficients of velocity and discharge due to entrance into pipes as follows:—Let c_d = the coefficient of discharge through varying lengths of pipes having an entrance such as A, Fig. 22, or B, Fig. 23.

Then it is found that with an entrance similar to A, c_d varies from 0·814 for two diameters in length to 0·099 at 3600 diameters. But when the entrance is similar to B, c_d varies from 0·986 for two diameters to 0·099 for 3600 diameters. When the length of the pipe is equal to 200 diameters the coefficients are similar in either case.



Figs. 22-23.—Flow through pipe.

64. In forming channels for the conduction of water care has to be exercised as to the manner in which the sides are sloped, and also as to the materials which would be best suited to the body of water moving through the channel; the sides of the channel will sometimes be composed of the earth from the excavation, or of material from some other situation. If the channel is steep and the velocity of the water very great, the sides must be formed of stonework or brickwork; but if the velocity is small, comparatively speaking, the embankment having been formed with earth and sown with grass seeds and aquatic plants or plants having a strong and spreading root, the slope of 1½ horizontal to 1 vertical or 2 to 1 will in all probability be successful in preventing the sides being washed away. The slope must depend on the tenacity of the earth, of which it is to be composed. Even a slope of 2½ to 1 has been adopted in some cases.

Many experiments have proved that a velocity of

30 feet per minute will not disturb clay with sand or stones.
40 ,, ,, ,, move coarse sand.
60 ,, ,, ,, ,, fine gravel (size of peas).
120 ,, ,, ,, ,, rounded pebbles 1 inch diameter.
180 ,, ,, ,, ,, angular stones 1¾ inch diameter.

But if slopes made with the materials thus enumerated for the varying velocities are protected with aquatic plants, they will stand even against these velocities. It must be taken into account that aquatic plants on the slope add to the friction and the velocity is decreased; therefore provision must be made in additional inclination to the channel compared with the inclination of a channel with sides free from these plants.

65. It is often required to convey the greatest possible quantity of water in an open channel with a given area of cross-section.

We know that the volume discharged is directly proportional to the area and inversely as the wetted perimeter. We have, therefore, to select a figure, which for a given area has the least border and for a given border has the greatest area. The student will easily prove this to be a circle.

66. It can be proved that for the best form of trapezoidal channels which are to have given areas and the sides to have certain slopes, the hydraulic mean depth should be equal to half the depth of the water in the middle of the channel and the width at the surface equal to the sum of the two side slopes.

CHAPTER IV.

EARTH PRESSURE AND RETAINING WALLS.

67. It is important that the sanitary engineer should have a thorough knowledge of earth pressures and retaining walls. He is constantly having walls of this character to deal with—*e.g.*, bridge abutments, walls of sewage tanks, retaining walls for earth and for supporting roadways, &c. It was a common occurrence to see walls, a few years ago, bulging out, and occasionally to see the remains of others that had fallen through faulty design. One even notices nowadays garden walls 9 inches thick which are intended to support five and six feet of earth, and even then are without weep-holes. It is the case that at times they retain their vertical and original shape for a few years, and then perhaps the effect of a storm throws the whole bodily over. It has been brought to the author's notice how walls have been thrown over on account of insufficient strength in sewage tanks; in one case it happened immediately the tank received the water which was to fill it; in another the walls were well built, but owing to weak design gave signs of collapse, and iron stays were put in to give the extra support required. It is desirable, therefore, that the development of the theory should be given both for earth and for water pressures.

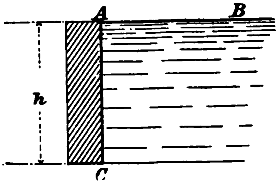


Fig. 24.—Action of water on a wall.

Water Pressure.

68. Retaining walls are subject to being overturned by external vertical and horizontal forces. These external forces may generally be set down as due to pressure by (1) water and (2) earth.

The internal forces resisting the external forces are confined to the material and composition of the wall itself.

69. We shall proceed to consider what effect water will have on a retaining wall. In Fig. 24, let A B be the surface of the water, and A C its depth. A C also represents the side of the wall retaining the water A B C.

The depth of the water A C = h, let w' represent the weight of a unit volume (a cubic foot) of the wall, l = length of the wall, b the breadth, and w the weight of a unit volume of water.

Then the pressure on a square foot at the foot of the wall C will be $h \times w \times l$.

From Mechanics we know that (1) the moment of a force with respect to a given point equals the product of the force into the length of the perpendicular drawn from the given point on to the line of direction of the force, and (2) if two forces balance each other, their moments are equal, and the system is in equilibrium.

The area of the wall $= h \times l$

$$\frac{h \times w}{2} \times h \times l = \text{average pressure on the wall} \quad . \quad (1.)$$

and $\frac{h}{3}$ is the distance of the fulcrum from the centre of pressure (a fuller explanation of these conclusions is given in Art. 40).

The external moment is therefore $= \frac{h^3 w l}{6}$. Similarly, the internal moment $= b \times w' \times h \times \frac{b}{2} \times l = \frac{b^2 l w' h}{2}$.

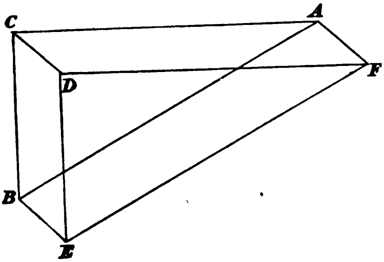


Fig. 25.—Pressure on an inclined surface.

For equilibrium these moments must balance each other, and for safety the factor x must be used—

$$\therefore \frac{b^2 l w' h}{2} = \frac{x h^3 w l}{6}$$

$$\text{and } b^2 = \frac{h^2 w x}{3 w'}$$

$$\therefore \quad b = h\sqrt{\frac{w x}{3 w'}}$$

70. We can obtain the pressure on an inclined surface under water by the use of trigonometry. In Fig. 25, let C D $= b$, C B $= h$, the angle C B A $= \theta$, and A B $= a$; also, let R = pressure on A B E F, and suppose A C D F to represent the surface of the water; the planes C D B E and C D A F are at right angles to each other, and they are respectively parallelograms.

$$\text{Then R} \sin\theta = \text{weight of A B C D E F} = \tfrac{1}{2} w \, \text{A C . B C} . b$$
$$= \tfrac{1}{2} w \, b \, a^2 \cos\theta \sin\theta,$$
$$\therefore \text{ R} = \tfrac{1}{2} w \, b \, a^2 \cos\theta = w \, . \, b \, . \, a \, \tfrac{1}{2} a \cos\theta.$$

To obtain the results of the previous Art.,

$$\text{R} = \frac{w b h^2}{2} \text{ when } \theta = o. \quad (2.) \text{ See (1) Art. 69.}$$

Now R makes an angle θ with the horizon,

$\therefore$ the horizontal component of R will be $\frac{1}{2} w \, b \, a^2 \cos^2\theta$.

The solid is kept at rest by horizontal pressure on B C E D, by its weight, and by reaction R.

$$\begin{aligned}\text{Hence pressure on B C E D} &= \tfrac{1}{2}\, w\, b\, a^2 \cos^2 \theta \\ &= w\, b\, a \cos\theta\, \tfrac{1}{2}\, a \cos\theta \\ &= w\,(\text{area B C E D})\,(\text{depth of middle point of B C}),\end{aligned}$$

which is the same as (2.) above, only obtained in a different manner.

Earth Pressures.

71. When we speak of earth pressures, it is understood to include all kinds of material that go to form the crust of the earth —*e.g.*, soil, gravel, clay, shales, rocks, &c.

Each kind of earth has its own distinct and separate angle of repose—*i.e.*, the angle made by the material, unsupported in any manner by outward agents and when in a state of rest. If a landslip is observed that has been exposed to the air for a number of years, it will be noticed that the slope is regular from the bottom upwards—this is the angle of repose for the material of which the slope is composed. A simple illustration is seen at the seaside, where the sand is dry; make a mound as high as possible, and the sides will have a regular and uniform slope; it is also noticeable that wet sand may be made to stand a certain vertical height, and then it will collapse.

Clay shales and clays are very hard when newly cut, and will remain vertical if so shaped, but on exposure to the atmosphere it soon crumbles down. Certain rocks are just the reverse; they are soft when cut, and on exposure to the weather become harder. Each must be considered on its merits as a stable earth. Rankine gives the following:—

	Greatest depth of temporary vertical face.
Clean dry sand and gravel, ...	0
Moist sand and ordinary surface mould, . .	3 to 6 feet.
Clay (ordinary), ...	10 to 16 feet.

Earth.		Angle of repose, α.	Coefficient of friction, μ.	Customary designation of natural slope, $\frac{1}{\mu}$ to 1.
Dry sand, clay, and mixed earth	from	27°	0·75	1·33 to 1
	to	21°	0·38	2·63 ,, 1
Damp clay, ...		45°	1·00	1·00 ,, 1
Wet clay, ...	from	17°	0·31	3·23 ,, 1
	to	14°	0·25	4·00 ,, 1
Shingle and gravel, . . .	from	48°	1·11	0·90 ,, 1
	to	35°	0·70	1·43 ,, 1
Peat, ...	from	45°	1·00	1·00 ,, 1
	to	14°	0·25	4·00 ,, 1

72. The following are the weights of a cubic foot of the ordinary materials of earthwork :—

Earth.	Cubic Foot.
Chalk,	117 to 174 lbs.
Clay,	120 to 135 ,,
Gravel and shingle,	90 to 110 ,,
Marl,	100 to 119 ,,
Mud,	102 ,,
Sand, Dry,	89 ,,
,, Damp,	118 ,,
Shale,	162 ,,

73. The agent which preserves the angle of repose is known as friction, the value denoted by the tangent of this angle is known as the coefficient of friction = μ.

74. The surface slope of the mass of earth whose pressure on a vertical plane is to be considered must, therefore, be either equal to or less than the angle of repose. In Fig. 26, let A B be the plane against which it is proposed to find the pressure of the mass of earth whose surface is A E. Then as B D makes with B C (a horizontal plane) the angle of repose of the earth (α), and A F is parallel to B D, A E, the surface of the mass, must not have a greater inclination to the horizon than A F. It will be at once apparent that if the surface were as shown by the line A G, it would not remain very long in that position, the portion G A F would soon slide over the point A, and leave the surface as A F.

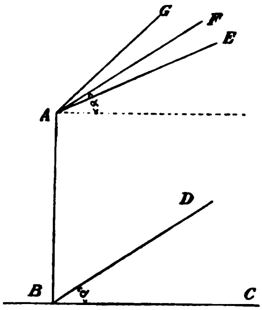


Fig. 26.—Pressure of earth.

75. The theory about to be explained is that of Rankine, and the matter as set forth here is more in detail than will be found in his work on *Civil Engineering*.

76. Internal stress is the name of the force which is exerted between the two parts of a body divided by an imaginary plane in any direction. In a fluid it is always normal, and is equal in intensity for all positions of the plane; in a solid the stress may either be normal, oblique, or shearing, according as the position of the plane varies.

77. If two planes traverse a point in a body, and the direction of the stress on the first plane is parallel to the second plane, then the stress on the second plane is parallel to the first plane. Such a pair are called "conjugate stresses," and if they are normal to their planes of application they are called "principal stresses."

78. The above remarks apply to the stresses in a solid which is a homogeneous mass with cohesion; they are now to apply to a

body which is not a solid, but, at the same time, is homogeneous without cohesion.

In a mass of earth, imagine the rhombic prism *b d e f* (Fig. 27) to be a particle on whose faces the pressure P is parallel to the planes *d e* and *b f*, and the pressure Q is parallel to the planes *b d* and *f e;* then these pressures are termed *conjugate pressures.*

79. The intensity and direction of the resultant stress can be determined in the cases (1) if the principal stresses are of the same kind and their intensities equal; (2) if they are not of the same kind, but their intensities are equal; or (3) if they should be of the same kind and their intensities unequal.

80. Case I.—In Fig. 28, O X Y is a particle just in equilibrium, P is the principal stress on the plane O X, and Q the principal stress on the plane O Y; they are both of the same kind, and as the particles are in equilibrium, the resultant stress on the third face must also be of the same kind (the three stresses would form a similar triangle to that of the figure; therefore R^2 would equal $P^2 + Q^2$), and their intensities must be equal to each other —*i.e.*, $r = p = q$.

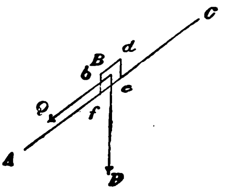


Fig. 27.—Conjugate pressures.

81. Case II.—The intensities in this case are equal—that is, $r = p = q$; but one of the stresses P and Q acts in a direction opposite to that shown in the figure. The particle is in equilibrium, therefore the resultant will make an angle with the direction ot P equal to that which R makes, but in an opposite direction, as shown by R′.

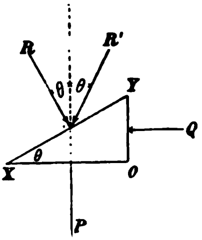


Fig. 28.—Incidence of forces on a particle in *equilibrio.*

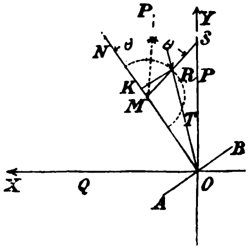


Fig. 29.—Incidence of force on a particle.

82. Case III.—The intensities are different, but the principal stresses are of the same kind. In Fig. 29, O X and O Y are the directions of the principal stresses, and A B is the third face on which the direction of the resultant and its intensity is to be found. Draw from point O the line O N normal to the plane A B, and along O N cut off O M equal to the mean of the sum of the in-

tensities $\frac{p+q}{2}$; with M as centre and M O radius cut O Y in S and join M S; from the point M along M S measure the length M R equal to the mean of the difference of the intensities $\frac{p-q}{2}$. Join R O. Then R O represents the direction and the intensity of the resultant stress.

The plane A B makes an angle with O X = θ.

$$\therefore \angle \text{NMS} = 2\,\theta.$$

As θ changes so will the angle M O R, and it will be a maximum when R O is the tangent to the circle with M as centre—*i.e.*, when M R O is a right angle.

When M R O is a right angle, its sine is $\frac{\text{MR}}{\text{MO}} = \frac{p-q}{p+q}$. If this theory is applied to earth, the angle M R O will be the angle of repose of earth = α.

Then sine α must be less than or equal to $\frac{p-q}{p+q}$,

$$\text{or } \frac{p}{q} \leqq \frac{1+\sin\alpha}{1-\sin\alpha}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

To find the intensity of the resultant so as to be expressed algebraically. Draw R K at right angles to M O.

$$\begin{aligned}
\text{Then RO}^2 &= \text{RK}^2 + \text{KO}^2 \\
&= \left\{\tfrac{1}{2}(p-q)\sin 2\,\theta\right\}^2 + \left\{\tfrac{1}{2}(p+q) + \tfrac{1}{2}(p-q)\cos 2\,\theta\right\}^2 \\
&= \left\{\tfrac{1}{2}(p-q)\right\}^2 + \left\{\tfrac{1}{2}(p+q)\right\}^2 + \tfrac{1}{2}(p^2-q^2)(\cos^2\theta - \sin^2\theta) \\
&= \tfrac{1}{2}(p^2+q^2) + \tfrac{1}{2}(p^2\cos^2\theta + q^2\sin^2\theta) - \tfrac{1}{2}(p^2\sin^2\theta + q^2\cos^2\theta) \\
&= \tfrac{1}{2}(p^2+q^2)(\sin^2\theta + \cos^2\theta) + \tfrac{1}{2}(p^2\cos^2\theta + q^2\sin^2\theta) - \tfrac{1}{2}(p^2\sin^2 \\
&\qquad \theta + q^2\cos^2\theta) \\
&= r^2 = p^2\cos^2\theta + q^2\sin^2\theta \\
\text{or } r &= \sqrt{p^2\cos^2\theta + q^2\sin^2\theta}.
\end{aligned}$$

It will be seen that this is a combination of the two cases previously considered; OM is taken at right angles to the plane A B, and M R makes the same angle with the direction of P as M O does. R O is the resultant intensity of two other resultant intensities, one being the intensity of the resultant of two like principal stresses having the same intensity $\frac{1}{2}(p+q)$, and the other being the intensity of the resultant of two unlike principal stresses of the same intensity $\frac{1}{2}(p-q)$. It will be at once seen that $p = \frac{1}{2}(p+q) + \frac{1}{2}(p-q)$ and $q = \frac{1}{2}(p+q) - \frac{1}{2}(p-q)$.

83. The ratio $\frac{p}{q}$ in (1) Art. 82 is that for the case when the

intensity p acts at right angles to the intensity q, and the value $q = \frac{p(1 - \sin\alpha)}{(1 + \sin\alpha)}$ serves to determine the least intensity of horizontal pressure of earth which will maintain the stability of a mass of earth through which a vertical pressure of an intensity p acts.

But it is required to determine the ratio $\frac{p}{q}$ where the pressures are not at right angles to each other.

Construct Fig. 30 in the same manner as part of Fig. 29, making $OM = \frac{p+q}{2}$ and $MR = \frac{p-q}{2}$. With M as centre and MR as radius, construct circle BSRC. OS is a tangent to the circle, and let the variable angle $ORM = \theta$. Then OB is the minimum value of OS and OC is the maximum value; when $\alpha = 0$, $\frac{p}{q} = \frac{OB}{OC}$, and when $\phi = \alpha$ then $p = q = OS$.

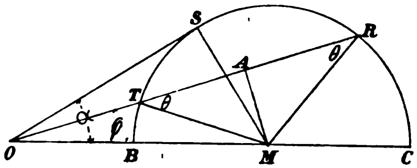


Fig. 30.—Ratio of pressures not at right angles.

AM is a perpendicular from M on OR, $AR = \frac{1}{2}(p - q)\cos\theta$, $MA = \frac{1}{2}(p - q)\sin\theta$, and $OA = \frac{1}{2}(p + q)\cos\phi$. Then

$$\tfrac{1}{2}(p+q) : \sin\theta :: \tfrac{1}{2}(p-q) : \sin\phi,$$

$$\therefore\ \sin\theta = \frac{\frac{1}{2}(p+q)}{\frac{1}{2}(p-q)}\sin\phi,$$

$$\text{and } \cos\theta = \sqrt{1 - \sin^2\theta} = \sqrt{1 - \frac{(p+q)^2}{(p-q)^2}\sin^2\phi}$$

$$= \sqrt{\frac{(p-q)^2 - (p+q)^2\sin^2\phi}{(p-q)^2}},$$

$$\text{as } \sin\alpha = \frac{MS}{OM} = \frac{\frac{1}{2}(p-q)}{\frac{1}{2}(p+q)},$$

$$\cos\theta = \sqrt{\frac{\{\frac{1}{2}(p+q)\}^2\sin^2\alpha - \{\frac{1}{2}(p+q)\}^2\sin^2\phi}{\{\frac{1}{2}(p-q)\}^2}}$$

$$= \frac{\frac{1}{2}(p+q)}{\frac{1}{2}(p-q)}\sqrt{\sin^2\alpha - \sin^2\phi}, \text{ or } \frac{\frac{1}{2}(p+q)}{\frac{1}{2}(p-q)}\sqrt{\cos^2\phi - \cos^2\alpha}.$$

$$OT = q = OR - 2AR = OA + AR - 2AR,$$

$$\therefore\ q = \tfrac{1}{2}(p+q)\cos\phi - \tfrac{1}{2}(p-q)\cos\theta.$$

Substitute for $\cos\theta$, and

$$q = \tfrac{1}{2}(p+q)\cos\phi - \tfrac{1}{2}(p+q)\sqrt{\cos^2\phi - \cos^2\alpha}$$

$$= \tfrac{1}{2}(p+q)\left\{\cos\phi - \sqrt{\cos^2\phi - \cos^2\alpha}\right\},$$

$$\text{and } OR = p = \tfrac{1}{2}(p+q)\left(\cos\phi + \sqrt{\cos^2\phi - \cos^2\alpha}\right).$$

$$\frac{p}{q} = \frac{\cos\phi + \sqrt{\cos^2\phi - \cos^2\alpha}}{\cos\phi - \sqrt{\cos^2\phi - \cos^2\alpha}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (a)$$

84. Having now found the values of p and q relative to each other, we may easily find the pressure of earth against vertical or inclined planes. In Fig. 31, let B C be the surface of earth, and A a particle of earth at a vertical depth h below the surface. Suppose one set of the planes of the surfaces of the particle be parallel to each other and to the surface of the earth, and the other set to be parallel to each other and vertical. The pressure on the particle will be equal to the weight of the vertical column F A. The intensity p of this pressure will be equal to the weight of the column multiplied by the cosine of the angle (ϕ) that the surface B C makes to the horizon. This will be evident, as the intensity will vary with the slope, and will be equal to the normal from the surface on to the particle, in this case = B A. In Fig. 30, O T = q, and O R = p; as the angle ϕ varies from 0 to α, so q varies in value from O B to O S, and p varies in value from O C to O S,

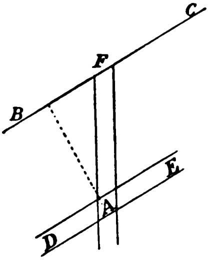


Fig. 31.—Pressure on earth particle.

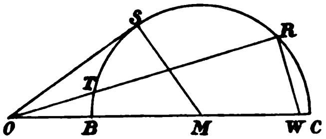


Fig. 32.—Ratio of pressure.

$$\therefore \quad p = wh\cos\phi \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (b)$$

Where w = weight of a unit volume of earth ϕ must, as will have been seen from Art. 83, be less than or equal to the angle of repose.

The pressure of the lesser intensity sufficient to preserve the stability of earth will be (combining equations (a) and (b), Art. 83)—

$$q = wx\cos\phi\,\frac{\cos\phi - \sqrt{\cos^2\phi - \cos^2\alpha}}{\cos\phi + \sqrt{\cos^2\phi - \cos^2\alpha}}$$

To represent the values of p and q graphically, construct Fig. 32 similarly to Fig. 30, making O R equal the length of the normal from the particle on to the surface.

Then q = O T multiplied by the weight of the unit volume of earth. Draw R W at right angles to O R.

$$\text{Then } \mathrm{OW} : \mathrm{OR} : \mathrm{OT} :: wx : p : q.$$

If the surface be horizontal, then it follows that

$$p = wx, \text{ and } q = wx\frac{1 - \sin\alpha}{1 + \sin\alpha}$$

If the surface coincide with the angle of repose α,

$$\text{then } p = q = wx\cos\alpha.$$

85. The average intensity of the resultant earth pressure on a vertical plane of the depth h will be

$$\frac{wx}{2}\cos\phi\frac{\cos\phi - \sqrt{\cos^2\phi - \cos^2\alpha}}{\cos\phi + \sqrt{\cos^2\phi - \cos^2\alpha}}$$

The total pressure will therefore be

$$\frac{wx^2}{2}\cos\phi\frac{\cos\phi - \sqrt{\cos^2\phi - \cos^2\alpha}}{\cos\phi + \sqrt{\cos^2\phi - \cos^2\alpha}}$$

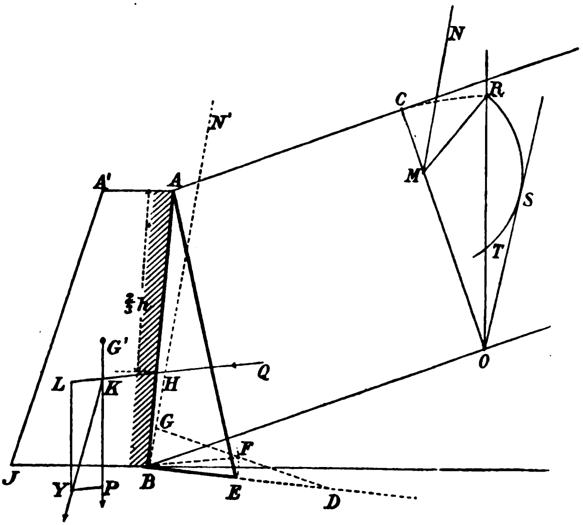


Fig. 33.—Thrusts against wall.

The application of the resultant thrust will be at $\frac{2}{3}h$ below the surface, as previously explained; its direction will in this case be parallel to the surface of earth.

86. A further and more complete graphical construction is given for a wall that is not vertical in Fig. 33. Let A B be the face of

the back of a wall, and A C the surface of earth; from any point O at a vertical depth h below the surface draw C O at right angles to A C, and make on R O a vertical line through O, R O = C O. Also draw S O making an angle α (the angle of repose) with O M. Find the point M by drawing the segment of circle R S T at a tangent to S O. Draw M N to bisect the angle C M R, and make the circle R S T cut the line R O in T. Then N M is the direction of the principal stress, R O = p, and T O = q.

From B draw B D at right angles to A B, and make B D equal to O M. Through the point B draw N′ B parallel to N M, and from D draw D G = D B; along D G from D cut off D F = M R, join F B, and this will equal the intensity of the resulting stress; from B on the line at right angles to A B make B E = B F, join E A, and the area of the triangle A B E will equal the area of pressure against the wall A B; this, multiplied by the weight w of a unit volume of earth, will give the total pressure. The pressure acts at $\frac{2}{3}h$ from the top of the wall—*i.e.*, through H in the direction Q H parallel to B F.

87. **Stability of the Wall.**—Let the wall A A′ J B have its centre of gravity at the point G′, from which drop the perpendicular line G′ P, produce Q H to L, and cut the line G′ P in K, measure with a suitable scale from K, the distance K L to equal the weight of the area A B E; with the same scale measure from K the distance K P, the weight of the wall A A′ J B; complete the parallelogram K L Y P, and join K Y. Then K Y will represent the direction of the resultant pressure of earth after passing through the wall; this line must be so devised that the direction will be in the middle third of the wall—*i.e.*, if the width J B be divided into three equal parts the line of the resultant must cut the middle part so divided. If the resultant were to cut the third nearest to B, then the heel of the wall would be receiving too great a proportion of the pressure, and the tendency of the wall would be to turn over with B as the hinge; on the other hand, if the third nearest to J were receiving the pressure, then the wall would probably be thrust out at the toe.

To prevent the wall from sliding, the angle which the direction of the resultant K Y makes with the horizon must be less than the angle of friction between the wall and earth.

When the surface of one substance A is placed on another surface of similar or dissimilar substance B, there is a certain angle of inclination of surface B when A will just be in equilibrium; this angle is the *angle of friction.* It will be found that this angle differs in a few cases from the angle of repose—*e.g.*, the angle of repose of damp clay is 45°, but the angle of friction for masonry on moist clay is 18¼°.

For the depth of foundations of walls, see Chap. XX.

88. Another method for obtaining the pressure of earth against

a vertical or other face is here given; it differs from that of Rankine.

In Fig. 34, let A B be the vertical face, E B D the angle of repose of the mass of earth, A C the surface of the mass.

The wall is subjected to a pressure which will obviously tend to turn it over, and about the toe F.

The theory is that the pressure of the mass of earth between the angle of repose and the vertical face is the only force the wall has to resist, and that a portion of this mass of earth is supported by the earth between B E and B D; that is to say, if the vertical face were suddenly removed, only a portion of the earth between B E and B A would move immediately, and that the friction of earth on earth on the line BE would retain the other portion, say B C to B E. Then B C may be assumed to be the breaking surface or surface of rupture. Let the angle between B C and BA be θ. The depth AB = h.

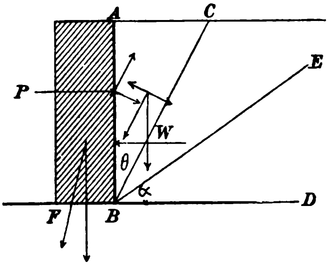


Fig. 34.—Pressure against wall.

$$\text{The weight of the prism A B C} = \frac{h \times \text{AC}}{2} \times w = h \times \frac{h \times \text{AC} \times w}{2h}.$$

$$\text{W} = \tfrac{1}{2} h^2 \tan \theta \, w.$$

This weight may be resolved into components at right angles and parallel to the breaking surface B C, which respectively will be

$$\left(\frac{h^2 \tan \theta \, w}{2}\right) \sin \theta \text{ and } \left(\frac{h^2 \tan \theta \, w}{2}\right) \cos \theta.$$

Let μ represent the coefficient of friction between the mass of earth and the wall or vertical face. Then the effect of the force of friction parallel to the face B C will be

$$\mu \left(\frac{h^2 \tan \theta \, w}{2}\right) \sin \theta.$$

Therefore the resultant pressure parallel to the surface of rupture is

$$\frac{h^2 \tan \theta \, w}{2} (\cos \theta - \mu \sin \theta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let P represent the force at right angles to the vertical face of wall A B; resolve this force at right angles and parallel to the face B C. Then the resultant pressure parallel to the face B C will be

$$\text{P} (\sin \theta + \mu \cos \theta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For equilibrium the resultant (1) must equal or balance (2)—*i.e.*,

$$\left(\frac{h^2 \tan\theta\, w}{2}\right)(\cos\theta - \mu\sin\theta) = \mathrm{P}(\sin\theta + \mu\cos\theta),$$

$$\therefore\ \mathrm{P} = \frac{w\,h^2}{2}\left\{\frac{\tan\theta(\cos\theta - \mu\sin\theta)}{\sin\theta + \mu\cos\theta}\right\}$$

$$= \frac{w\,h^2}{2}\left\{\frac{\sin\theta\,(1 - \mu\tan\theta)}{\sin\theta + \mu\cos\theta}\right\}$$

$$= \frac{w\,h^2}{2}\left\{\frac{1 - \mu\tan\theta}{1 + \mu\cot\theta}\right\}.$$

The maximum value of θ will be found by means of the Differential Calculus—*i.e.*,

$$\frac{d\left\{\dfrac{1 - \mu\tan\theta}{1 + \mu\cot\theta}\right\}}{d\theta} = 0 = \frac{-\mu\dfrac{1}{\cos^2\theta}}{1 + \mu\cot\theta} + \frac{\dfrac{\mu}{\sin^2\theta}(1 - \mu\tan\theta)}{(1 + \mu\cot\theta)^2}.$$

Solving this, we find that $1 - \mu\tan\theta = \tan^2\theta\,(1 + \mu\cot\theta)$, and

$$1 - \tan^2\theta = 2\mu\tan\theta,$$
$$\therefore\ \mu = \cot 2\theta,$$
$$\text{and }\ \theta = \tfrac{1}{2}\cot^{-1}\mu,$$

i.e., θ is half the angle whose cotangent is equal to μ.

But μ is the tangent of the angle of repose, and consequently the complement of this angle is twice the angle required; therefore, if the angle A B E be bisected by B C, we have the triangular prism A B C, which, multiplied by the length at right angles to the page, is the volume giving the maximum thrust against the wall.

Having found P by inserting the value of θ, it acts at $\frac{2h}{3}$ below the surface A C. Let b = the thickness of wall and w' = the weight of a unit-volume of the material of the wall; then, taking moments about the point F,

$$\frac{\mathrm{W}h}{3} = (h \times b \times w')\frac{b}{2} + \mu\mathrm{P}b.$$

The resultant of P and W should cut the middle third of the base and follow the laws of stability as set forth in Arts. 86 and 87.

The principle involved in the case, when the retaining wall is vertical and the surface of the mass of earth is horizontal, has been given; for the cases where these conditions are varied, the construction and result will be apparent.

CHAPTER V.

POWER.

89. The sanitary engineer, although he may not be a mechanical engineer, must have such a knowledge of machinery or mechanical power as will enable him to carry out his schemes to a successful and economical issue.

In many cases it is advisable that the sewage should be raised to a certain height, and it is necessary that the engineer should know of the various agents for overcoming this difficulty—*e.g.*, water, steam, or electricity, compressed air, &c., and the power that each may be calculated to yield.

90. "Horse-power" is the term which is used to denote the unit of work performed by a machine. Watt was the originator of the term; he estimated that a horse could perform work at the rate of about 22,000 foot-pounds per minute, but he allowed 50 per cent. more, and took 33,000 foot-pounds as his measure of the work of a horse. This arbitrary decision has become the standard unit measure of a machine. The word "Power" may be understood to mean the rate of work, and a horse-power involves the performance of 33,000 foot-pounds of work in every minute. The work of raising 1 pound 1 foot high in a minute is a measure of work, and is called "foot-pound."

It will thus be seen that if 1650 lbs. of water had to be lifted 20 feet high in one minute it would require a machine capable of developing 33,000 foot-pounds in a minute or 1 horse-power.

91. The "Indicated horse-power" of an engine is the product of the steam pressure per square inch on a piston throughout its stroke, the area of the piston and the speed of the piston.

Let P represent mean pressure on piston in lbs. per square inch.
A ,, area of piston in square inches.
R ,, revolutions of crank per minute.
S ,, stroke in feet.

Then 2 S R = speed of piston in feet per minute. Therefore,

$$\text{indicated horse-power (I.H.P.)} = \frac{2\,R\,S\,P\,A}{33{,}000}.$$

92. The efficiency of an engine is of great importance in finding the size or power of engine required. An engine is working well if 85 per cent. of its indicated horse-power is being used in external work, the remaining 15 per cent. is lost in friction in the bearings of the engine itself. Again, when pumps are connected to the

engine there may be a further and serious loss in the "slip" of the water through the valves of the pumps; in the best force pumps 5 per cent. for slip would be none too little to allow.

There may be pumps and engines combined which will give a greater efficiency than is set forth above. These figures are, however, a fair and reasonable average of a machine's efficiency.

The indicated horse-power, together with these allowances, will then represent the useful power of the machine.

Engines work most economically when running at their normal speeds—that is to say, an engine working at either its lowest or highest speed will not have as high a mechanical efficiency as when it is running at its normal speed. Again, machines and steam boilers when working continuously (day and night) are more efficient than when working intermittently—a fact which must be self-evident.

There are similar contingencies to be taken into account when considering the dimensions of boilers. If the steam pressure at the boiler is taken there will be a reduction in that pressure when it reaches the cylinder. This, however, depends mainly on the length of the pipes connecting the boiler with the cylinder, and will therefore vary in each case. The power of a steam boiler is set forth in Chap. XIX., Art. 384.

93. In small installations it may be economical to put down gas engines or electrical motors. Electrical power is so much in the hands of local authorities that it would be surprising if motors were not used in preference to steam power, the working expenses would be so greatly reduced and the electrical plant serving other purposes would have a day load, which is a desirable acquisition in an electric-power station.

94. **Electrical Terms.**—The relations between water and electric power in their terms will be easily seen, and by comparison more easily understood.

The *ohm* is the term representing the resistance of the conductor to the passage of the current (as the velocity of water in a pipe is retarded by the friction of the sides of the pipe). The standard ohm is the resistance between the copper terminals of the Board of Trade standard instrument to the passage of an unvarying electrical current, when the coil of wire between the terminals is at the uniform temperature of 15·4° C.

The *ampere* is the measure of the current which is passing through the conductor (as velocity is the measure of the speed of water through a pipe); the standard unit is the current which is passing in and through the coils of wire of the instrument when, on reversing the current in the fixed coils, the change in the forces acting upon the suspended coils in its sighted position is exactly balanced by the force exerted by gravity upon an iridio platinum weight.

The *volt* is the measure of the pressure of the current (as pressure of water is the measure of the weight of water on a unit surface), the standard is the hundredth part of the pressure which, when applied between the terminals of the instrument, causes a certain rotation of the suspended portion of the instrument between two given marks A and B.

The coils and instruments are deposited at the Board of Trade Standardising Departments, Whitehall, London.

A *watt* is a measure of the power of electrical current (just as the velocity of water multiplied by the pressure is the power of water); it is the power developed or rate of doing work in a circuit with a difference of one volt at its terminals when a current of one ampere flows through it—*e.g.*, the work done by a dynamo which has a current of 20 amperes and 100 volts to a circuit is 20 × 100 = 2000 watts.

An *electric horse-power* is equal to 746 watts, therefore the horse-power of the dynamo in the previous paragraph is—

$$\frac{2000}{746} = 2{\cdot}6.$$

95. The *Board of Trade unit* is 1000 watt-hours—that is, the energy in watts multiplied by the number of hours this energy is supplied and divided by 1000 will give the number of Board of Trade units (B.T. units). It is a convenient quantity or expression instituted by the Board of Trade, who have stipulated that when stations supply energy it shall be charged for at a rate per B.T. unit.

For comparison—

1 watt = $44\frac{1}{4}$ foot-lbs.
1 kilowatt = 1000 watts = $1\frac{1}{3}$ horse-power.
1 B.T. unit = $1\frac{1}{3}$ horse-power per hour.

This electrical information is given here in brief form; no doubt it will be appreciated by the sanitary engineer who will be able to convert the horse-power of a machine into electrical units.

96. Two other important agents for the transmission of power that have been mentioned are water and compressed air.

Water or hydraulic motors, where water is plentiful and with sufficient head, would be very economical; they have not been extensively adopted, probably on account of their not having been favoured by manufacturers. Fig. 35 shows the patent water motor designed by Messrs. W. H. Bailey & Company. This particular motor has a water cylinder, A, which is 4 inches diameter, and has a 12-inch stroke. The rams, marked B, are $4\frac{1}{2}$ inches diameter. The quantity of water which can be raised 100 feet is about 600 gallons per hour. The head of water which is employed to work the pump is 290 feet. This apparatus was made for the Blackrod Urban District Council. The advantages of such a system of raising water must be apparent.

The working parts are very simple, the valves being the speciality of the patentees; these are in the box C. The supply of water enters the air cylinder D, which assists in keeping an even and regular pressure; after the water passes through the valves and cylinder, it passes through the outlet E. The suction and delivery pipes are marked F and G respectively.

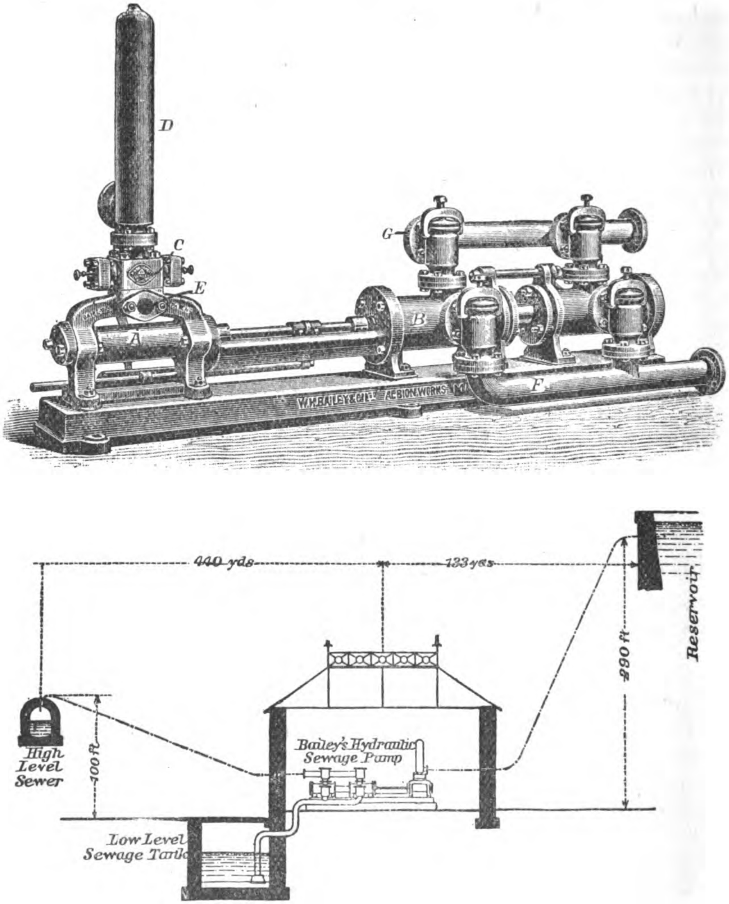


Fig. 35.—Bailey's hydraulic sewage pump.

97. In a water motor it will be understood that it does not necessarily absorb a large quantity of water to work the machine, the greater the head the less will be the quantity required, as will be seen from the following example:—It is known that when pressure is communicated to any part of a fluid, it is transmitted equally in all directions through the fluid—as a consequence of this principle, which is known as Pascal's, a quantity of water, however small, can be made to support a weight, however large. In Fig. 36, let B C be a long narrow pipe communicating with a vessel, A D, into which a piston, A D, is fitted. Now, let water flow into the vessel, it will rise in the tube B C to the level of A; but if a weight, W, be placed on the piston A D, and more water poured into the tube until the piston regains its position, A D, it will be found that the water rises in the tube B C to C, where it will remain in equilibrium. Therefore the pressure exerted by the water in the tube above the level of A supports the weight W. This pressure is communicated to every element of area of A D equal to the sectional area of the tube B C, and the pressure on A D is as many times greater than the weight of the water in C A as the area of A D is greater than the area of the tube.

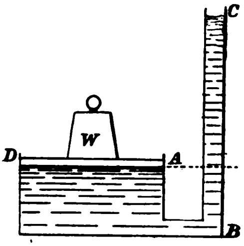


Fig. 36.—Transmission of pressure.

Let a = sectional area of the tube.
w = weight of unit volume of the water.
A = area of piston.
h = height A C.

$$\text{Then } a \times h \times w \times \frac{A}{a} = A \times h \times w = \text{pressure on A D.}$$

$$\therefore\ W = A \times h \times w$$

$$\text{and } h = \frac{W}{Aw}.$$

To apply this to a water motor, W would be the weight of water obtained by the height it has to be raised. To obtain the pressure, allowances would have to be made for friction through the length of the pipe from the source of supply to the engine, and also the friction through the valves and the working parts of the pump.

98. The transmission and utilisation by pneumatically or hydraulically devised machines is being adopted with more favour than has been in the past. Pneumatically-driven machines are more often in evidence than those driven by water power. This is not only the case with machines connected with sewerage works, but also with tools and machines in very many up-to-date workshops,

the reason being that air is more easily confined and distributed. Should any leakage occur it does not cause the amount of damage or annoyance that would happen under similar circumstances from a hydraulic apparatus. When power is required in any given situation there is always air available, but water may have to be brought to the place and its storage may take up considerable space and expense; also the air after having been used is passed into the atmosphere, whereas the waste water has to be conveyed to some water course or drain.

Professor Unwin states that for hydraulic transmission an excessive pressure must be used, in fact the pressure is usually 750 lbs. per square inch; but with air more power can be transmitted through a 6-inch main with 45 lbs. air pressure than with 750 lbs. water pressure, because with air a velocity 20 times greater than that permitted with water can be allowed without incurring any practically appreciable loss in friction in transmission. With air the quantity adjusts itself to the work to be done in consequence of its expansion, but with water the quantity used depends only on the size of the motor cylinder, and is always the same whether the resistance be great or little.

Air is 820 times lighter than water, therefore the power required to transmit air at atmospheric pressure may be 820 times less than for water at the same velocity.

99. Let x be the height in feet to which a body of water is required to be raised. The weight of a body of water 12 inches high on an area of 1 square inch is 0·434 lb.

Therefore $x \times 0{\cdot}434$ will give the air pressure in lbs. per square inch above that of the atmosphere, which must be supplied to the pump or ejector in order to raise the water.

The indicated horse-power is found as follows :—

Let y = gallons per minute supplied to the ejector. Then

$$\frac{x \times y \times 10}{33{,}000 \times 0{\cdot}4} = \text{I.H.P. of ejector,}$$

0·4 being the coefficient for losses which varies with different machines.

CHAPTER VI.

HOUSE DRAINAGE.

100. WHEN Queen Victoria in 1894 desired to reside at one of the palaces in Italy, it was a stipulation that the drainage should be thoroughly overhauled by an English engineer and altered as he might desire, an eloquent testimony to the sanitary efficiency of the designs of English experts.

But at the present day in many places within a short radius of large manufacturing towns there are villages unprovided with any satisfactory system of sewage disposal. The drains from individual houses or from a number of houses will run into a field within two or three yards of a dwelling-house; there the sewage is deposited from year end to year end without any attention, and the place becomes one great mass of unwholesome filth. This is no imaginary sketch, but one of actual fact. The author had to inspect and report on the drainage of several villages all within a distance of 3 miles from a populous manufacturing town, and found the sanitary conditions as described. In one case the drains from about twenty houses discharged into a garden in the front of several cottages. The garden was, in parts, about 6 inches deep with sewage. In other cases it ran down an open ditch in the roadway, and in a few others it drained into an open watercourse that eventually discharged into a river passing through the town. We hear that in some parts of the British Isles, animals—*e.g.*, pigs, &c.—are provided with a bed in one of the rooms of the cottage in which the owner lives.

The formation of Urban, Rural District, and Parish Councils are doing a great work in abolishing these abominations; and it is pleasing to note that in almost every district and village sanitary inspectors are being appointed, who with the powers they possess are rapidly converting these anomalies, which soon must become things of the past.

101. Sewerage schemes in miniature can be made for large mansions; it would be an uncommonly rare case to find any large house without some satisfactory means of disposing of its refuse. This being the case it must be possible for even small hamlets to be similarly drained and the sewage equally well disposed of. The work of sewage disposal is, if anything, becoming cheaper; it is well that Councils should be educated to this fact, as the inhabitants will then benefit by it in health and therefore in prosperity.

There are other matters in close touch with the drainage of houses which should not be lost sight of. The width of streets, areas, back-yards, and passages has an appreciable influence on the health of the inhabitants of a district. The Local Government Board some years ago formulated a set of model bye-laws, which are for the guidance of Local Authorities in preparing bye-laws for their districts. These bye-laws give power to the authorities to enforce certain widths for both front and back streets—the front street being generally fixed at from 36 to 40 feet in width, and the back street from 10 to 18 feet; also if the back street should exceed 200 feet in length without communication between the front and back streets except at the ends, a cross passage may be enforced at about half the distance. This is required so that a better current of air may obtain in the front and rear of the houses. But this is not the only advantage, as there is the convenience of taking a cart to the rear of the houses for the removal of the refuse.

102. One of the great factors in obtaining thorough ventilation to houses is to build them detached or semi-detached, with a wide street, ample yard space, a wide back street, and the buildings themselves not too great in height.

The rear of the houses and cottages should not be in such a state of confinement, or the backs of houses should not be so close to each other, that a proper and adequate circulation of air cannot get to the yard or ground of such yard. The model bye-laws go far enough to prevent this confinement, and if they are adopted in their entirety no doubt the people will benefit, but in many places it would be impossible to strictly enforce them; they ought to be capable of amendment to suit the requirements of these places, but not be so amended as to alter their general intention.

103. The majority of the population of this country live more than half their lives in the back portion of the house; these, therefore, are the persons, living in close confinement, that require more consideration from a sanitary standpoint.

It must be a *sine quâ non* that the gases from sewers should not enter the house or be in close proximity to it—that is to say, they must be removed to such a distance that they will not be inhaled by any person.

The question of ventilation of the present sewers has been a subject of controversy for the past half-century, and it is doubtful whether even now the many methods of ventilating serve the purpose for which they have been intended and designed; the subject is still one of importance; new theories are advanced frequently, but the real work of purifying the air in the sewers and the atmosphere has not advanced in the proportion one might have expected. Undoubtedly the question is one of peculiarities—one system might not obtain in any but one town—the conditions regulating the velocity of air currents are so dissimilar, that it is impossible to obtain one general design to suit all cases.

104. The sanitary engineer prevents foul air from entering houses through the drains, by placing traps provided with a water seal in various suitable positions. These traps are termed *intercepting traps*; they may be made to prevent the air from going forward by diverting it into a new direction, or be the means of merely cutting off the drainage of the house, or part of the house, from the sewerage system generally.

Where there is a back street, the drainage runs from each house direct to the sewer in that street; but where houses are in blocks of two or more, with a narrow passage between each two houses, there is no back street (this method of building houses is common to very many towns throughout the kingdom), and the drainage of the houses pass through and across the yards of the houses into the sewer in the passage, which discharges into the sewer in the front street.

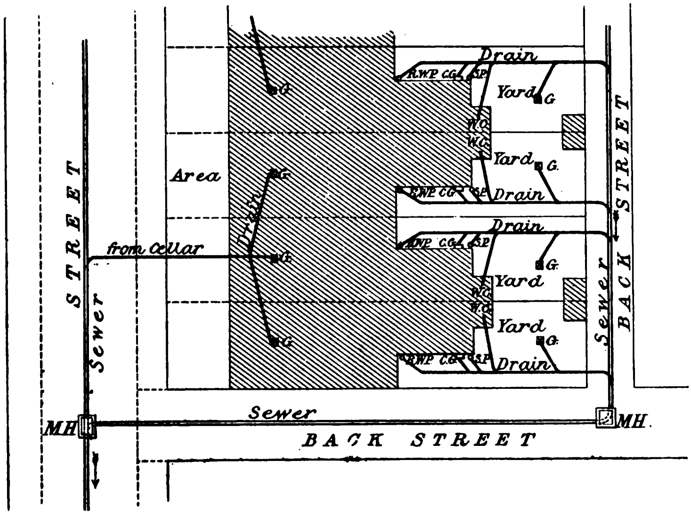


Fig. 37.—Plan of sewers.

105. Fig. 37 gives an illustration of the drainage of houses having a back and front street. The sewers in the back streets are shallow, just sufficient to take the drains which discharge on the surface of the yards. The manhole at the junction of the back streets would have an interceptor trap, or instead a light aluminium flap placed over the discharging pipe; this flap allows the air to come down the sewer, but prevents any quantity from passing any higher. The manhole with a flap on the sewer may otherwise be built as shown in Fig. 113.

106. The house drains should have a fall of 1 inch in 36 inches,

and the joints should be made in cement. It is sometimes the case that at slight bends, straight pipes are cut at an angle so that the line of pipes may be diverted; these should never be allowed; shaped bends should always be insisted upon at every change of direction. The sewer in the front street will be 9 to 12 feet deep, in order to take the water from the cellars; the gullies in the cellars should have a deep seal, and the water area be small superficially in order to prevent the evaporation which takes place, especially in those cellars that are not often used.

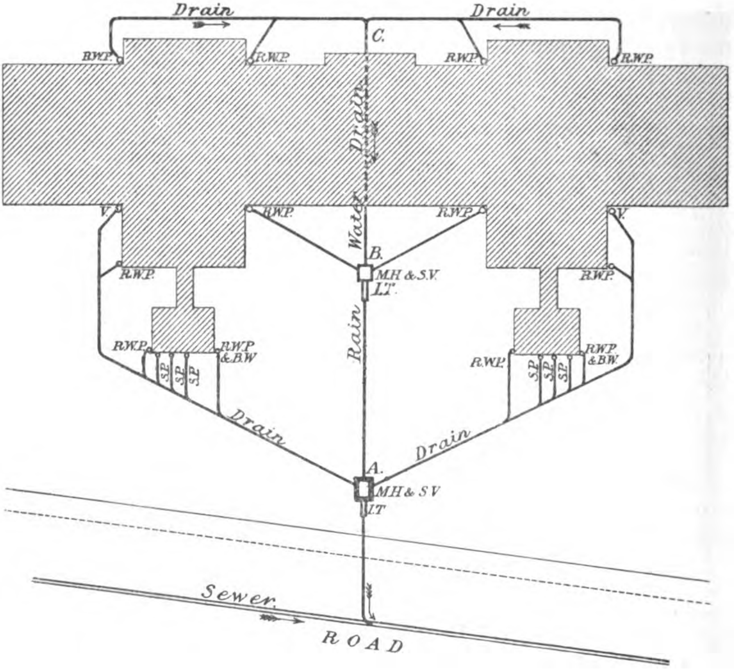


Fig. 38.—Plan of drainage of large building.

107. Fig. 38 gives an illustration of a large building—*e.g.*, hospital. The interceptor trap at manhole A is to prevent the gases from the main sewer penetrating past this manhole. The manhole cover is an open one, and is used as a surface ventilator or air inlet, ventilating or up-cast shafts being placed at the head of the drains. The intercepting trap in manhole B is to prevent the gases which may possibly gather in manhole A from penetrating into the building. Beyond B the drain is for clean water only (there should therefore be no objection to it going under the building); whenever a rainstorm occurs, the water having once

arrived at C gives a good direct flush into the main sewer. B also is a surface ventilator, but it will be seen that no sewer gases can ever get so far as this. The dotted portion of the drain should be laid in and covered with cement concrete. The ventilators are shown by the letters V.

108. It is desirable that a definition be given of the two terms "drain" and "sewer."

A *drain* is a sewer which is not repairable by the Public Local Authorities until two or more houses drain into it. According to this legal definition a drain may be a sewer, even should it run under a block of houses, and be unapproachable without entry into the buildings; it may be a sewer if it run through gardens, yards, or other private premises, immediately the second house drains into it. Such are the rulings on the distinction given in the Public Health Act, 1875. Whether the law as demonstrated is a just one or not is questionable; when it was draughted, the deficiencies in its thorough explanation would not occur to the draughtsman. It would be only a reasonable decision to call a drain a sewer when two or more houses drained into it and it had entered a public highway, thoroughfare, or street. As it stands, the cost of repairing defective drains is a very costly one, not for the direct repair, but on account of the peculiar places in which sewers are sometimes found; the compensation for damage in passing through private property may be a considerable sum.

From Sec. 19 of the Public Health Act, 1890, it may be construed that a drain may not be a sewer if the houses draining into it have different owners; it is then a common drain, and is not repairable by the public until it discharges the drainage of the last house. It is a peculiar construction, and liable to peculiar results; indeed, the decisions in the Courts reduce the reading of the Section to an absurdity, *e.g.*, In one case (Self *v.* Hove Commissioners) it was decided that a private drain into which the water closets of two houses were drained was repairable by the owner. In the case (Hill *v.* Hare) the Urban Sanitary Authority had never approved of, adopted, or repaired a culvert receiving the drainage from several different houses belonging to different owners. It was admittedly out of repair, and gave rise to a nuisance; the Justices dismissed the information on the ground that the culvert was a sewer vested in the Local Authority. Justices Cave and Lawrence upheld the decision of the Lower Court. But Justice Cave, in another case (Seal *v.* Merthyr Tydvil Urban District Council), stated in the course of his judgment that "If, however, in that case (Hill *v.* Hare) the drain was, properly speaking, a private drain, that case was wrongly decided." Lord Russell also upheld the decision of the County Court Judge who decided in favour of the Corporation in the case (Bradford *v.* Mayor of Eastbourne) where the Corporation served a notice upon several owners of houses in the same road, which were all connected with the public sewer by one common conduit pipe laid through private property, being in such a condition as to be a nuisance and dangerous to health to do the necessary work of repair. The decision in this case is that Section 41 of the Public Health Act must be complied with. There is thus this anomaly that a conduit is to be a sewer until a nuisance arises, when it changes to a drain repairable by the owner. Mr. Justice Wills, in the case (Bradford *v.* Mayor of Eastbourne) made some remarks very pertinent to the reading of Section 19—"It seems to me that the Section shows clearly what is meant. The private drain is contrasted with the public sewer. The public sewer is obviously here meant to indicate a sewer which serves the public generally, and has, or may have, an indefinite number of houses connected with it, either directly, or because branch sewers come into it; whereas the private drain serving two or more houses is that of which the natural use is confined to those houses, and with which other drains belonging to other houses could not be connected without the consent of the person through whose land it runs. The provision so understood does not seem to be unreasonable. A drain of this character is generally an economic substitute for separate drains from each of the houses served by it to the public sewer. As a rule, no public use can be made of such a drain, and there does not seem any reason in the nature of things why the owners of houses so drained should, by reason of the mere fact that two or more of them use the same private drain, escape the burden which would fall upon them if each house ran its drain direct to the public sewer."

109. The depth of the sewer in the front street has already been alluded to (Art. 106), that in the back street is shallow to allow for the collection of the liquid from surface, slop water, water closets, and rain-water drains.

Where there are many drains that can be made to radiate from a centre to the different points of discharge of a block of buildings or house, an intercepting trap is placed at this centre as near to the sewer as possible, but in the land attached to the buildings; this trap and chamber must be placed on the deep drain, as shown in Fig. 38. The trap itself would be constructed in the way shown in Fig. 39. The junction A is an opening into the manhole, and is hermetically sealed with a disc. If this is not done the trap is of no value. The tube, of which A is the disc covering the opening, is placed there in order that cleaning rods may be sent into the sewer to remove any obstruction.

The author has seen these intercepting traps placed about 9 feet deep, the manhole or chamber being about 18 to 24 inches square, it being impossible for any person either to examine the trap or to use the cleaning rods. The rods are rarely less than 3 feet long. It has also often been noticed that when the man goes down to remove some obstruction in the drain below **A**, the cap or disc is removed, laid on one side, and forgotten, causing considerable annoyance, as it becomes a ventilator for the sewer gas.

110. The intercepting trap should be placed in a position where all the sewage will necessarily pass through it, if possible including the water from the cellars. It has already been mentioned that the traps in cellars are often dry if not attended to; thus the air from the sewer would have free access into the house were it not for the trap so placed. This point should be particularly considered in laying out the drainage of habitable and other establishments, such as hospitals, schools, hotels, &c. In Fig. 37, the drainage of the cellars is shown to run direct to the sewer; this drain may be

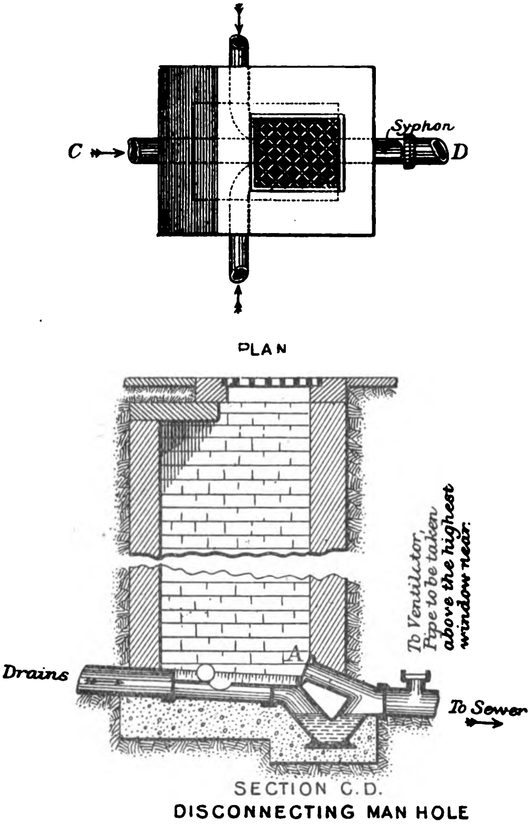


Fig. 39.—Plan and section of sewer below road

connected to the sewer below the water line of the sewer, thus forming a trap at the sewer itself.

The trap should be placed in the most central position possible, and the drains radiating thereto should be the shortest practicable so as to bring about the removal of the sewage and its disconnection from the houses as speedily as may be.

111. Although the gradients of house drains vary in different towns from 1 in 30 to 1 in 40, the generally-accepted rule is 1 in 36

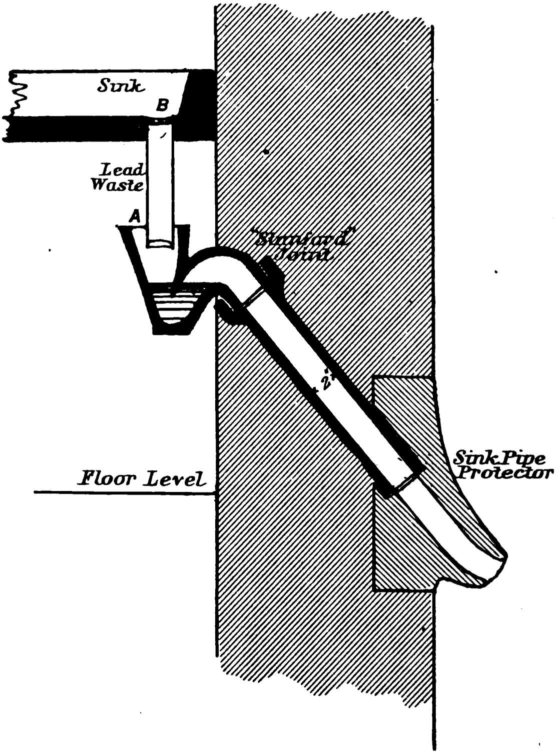


Fig. 40.—Duckett's (modified) sink fittings.

(Art. 106). This quick inclination is to, if possible, give a self-cleansing velocity to the small quantities of liquid that are discharged into the drains, and ensure their rapid removal from the proximity of habitable dwellings. In Art. 64 is given a table which shows the velocities that will remove certain materials. These, of course, apply only when the water is greater in bulk than the solids. It will be understood that the sewage from houses is not generally of such volume that large articles could be so carried away from the drains, and that the sewage itself contains solid matter in the form of sediment and excreta; it must be arranged that the inclination should not be so great as would allow the liquid to attain a greater velocity by its mobility than the large fæces which should accompany it, which would be left behind to form an obstruction to the flow. The inclinations given above have been found to answer these conditions very satisfactorily, being neither too great nor too small.

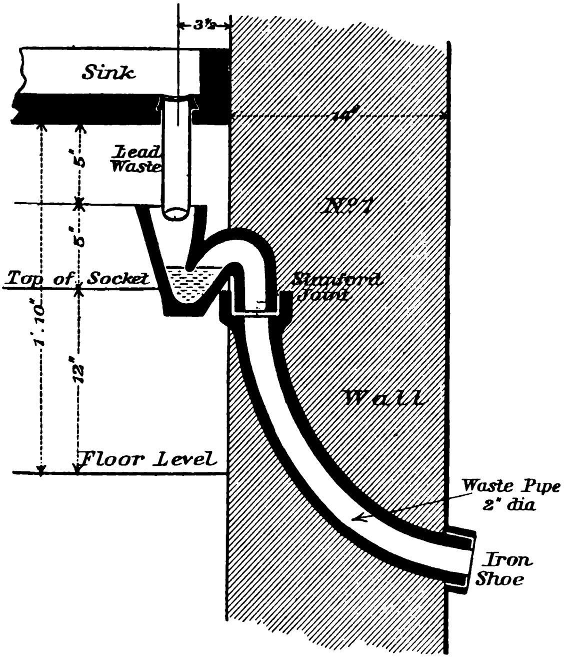


Fig. 41.—Duckett's sink fittings.

The size of drains should be at least 6 inches in diameter; they should be of well-glazed earthenware material and be connected by cement or other water-tight and dirt-proof joint. Smaller pipes may be used for such drains as those from down-spouts and where trapped gullies with immovable gratings are used, but from water or other closets 6-inch pipes are not too large.

A 6-inch drain with an inclination of 1 in 40 will take the sewage from ten average houses; it is therefore evident that a 6-inch pipe for one house is much too large, *prima facie*, for the work it has to do; but, in some mysterious manner, large quantities of grease, pieces of soap, rags, dishcloths, and many other articles enter the drains and easily choke one smaller in size.

The sewer should be greater than 6 inches in diameter when the branch drains are greater in number than five for each side, and the inclination of the sewer is at least 1 in 40. When the size is to be increased, it should be to at least 9 inches, as any pipe of intermediate diameter is liable to be more quickly obstructed in a smaller pipe by the deposit of such articles as those mentioned in the previous paragraph, and by the water that discharges from the many branch drains from both houses and streets on each side.

The sewer in the back street will depend for its size on the fall obtainable and the area it has to drain; this dimension will be ascertained by the method indicated in Chapter XII. and Art. 58.

112. The sink waste-pipe should always be trapped underneath the sink-stone by either a lead or earthenware trap. The latter may be constructed as shown in either Fig. 40 or 41. The trap is easily examined through the open space A. But, in case a lead trap is used, the solid drawn traps are the most suitable. At the underside of the trap there should be placed a brass screw plug, in order that the syphon may be cleaned and freed from any grease or other filth which may have accumulated. The diameter of the pipes should be at least $1\frac{1}{4}$ inches. The length of the pipe after it leaves the trap should be as short as possible in order to prevent the unsealing of the trap by an excess pressure of water, the preventive of which would be a ventilating pipe into the open air from near to the top and discharge side of the trap (Fig. 43); this ventilator provides air to the trap in case a vacuum should be formed (see Art. 51).

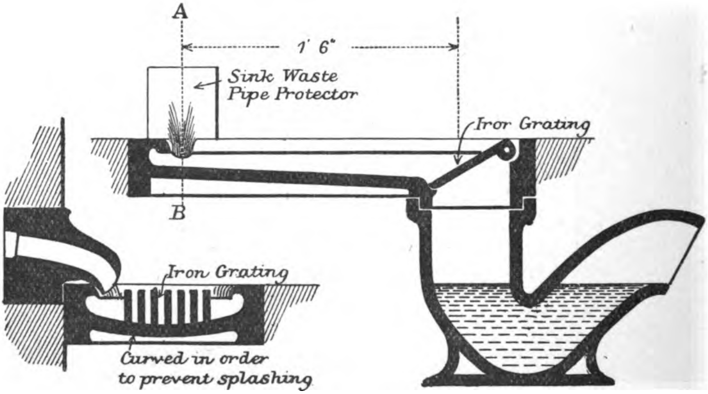


Fig. 42.—Channel gully.

It is a good plan to have an immovable grid at B of not too large a size and with many small holes about ⅜-inch diameter, so that only water and grease can get through to the trap; this form of grid also prevents the water from getting into the waste-pipe at a rapid rate, and, as a consequence, assists in preventing the unsyphoning of the trap when a ventilating pipe has not been provided. To unsyphon the trap, it will be seen that the rate of flow through the waste-pipe must be of such a volume as will fill the pipe below the trap with water; the provision alluded to will avoid this.

113. In the model bye-laws the sink waste must deliver into the open air, and pass along an open channel for a distance of 18 inches before entering the gully which discharges into the drain. By this arrangement any foul air from the gully is mixed with atmospheric air before it arrives at the sink waste pipe. Such gas so mixed cannot even then pass the syphon, which has been placed on the latter. Figs. 42, 43, and 44 show forms of channels and gullies combined, which explain themselves.

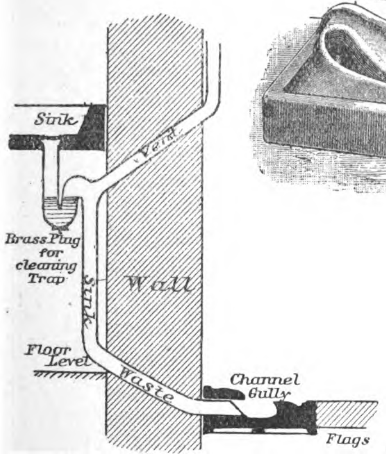


Fig. 43.—Usual method of dealing with sinks.

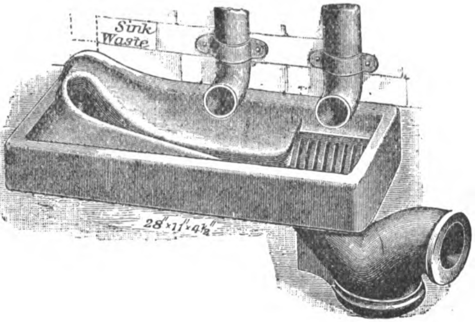
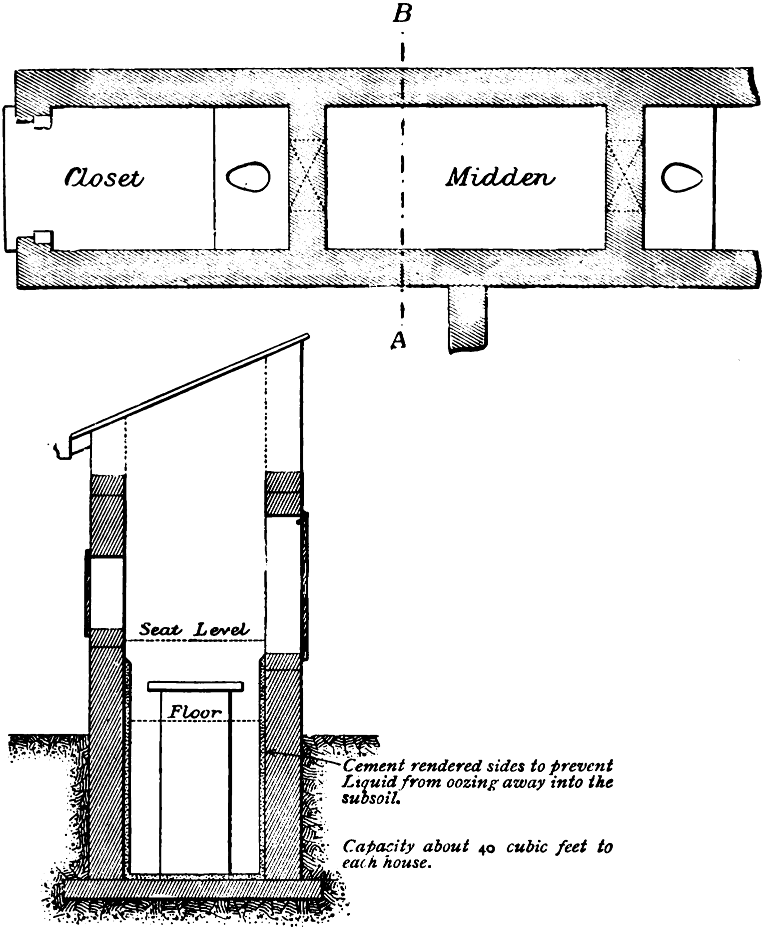


Fig. 44.—Duckett's self-cleaning channel gully.

114. The **wet midden**, or privy and ashpit combined, was the original method of collecting the excreta refuse from houses, and even in the last decade town authorities have allowed this form of closet to be placed in new houses. The Public Health Act, 1875, enacts that a closet, &c., shall be provided, but whatever is constructed must be of such a type as will not be a nuisance and a danger to health. These privies are both a nuisance and a danger to health,

and should never be allowed. Fig. 45 shows the closet and midden as usually built, the midden or pit is more often than not constructed of brickwork without any cement rendering. The liquid, as a consequence, percolates through the brickwork sides,



Cement rendered sides to prevent Liquid from oozing away into the subsoil.

Capacity about 40 cubic feet to each house.

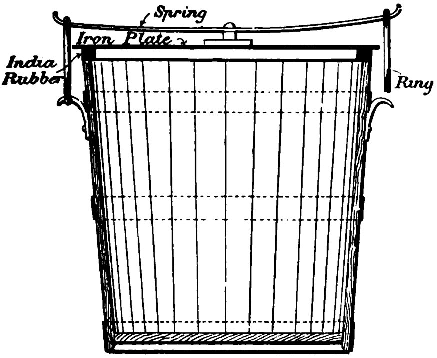
SECTION A B.

Fig. 45.—Wet midden.

contaminating everything in the immediate vicinity; generally they are built not far from the houses which they are intended to serve. It is pleasing to note that they are being condemned, and are being superseded in most places by either the pail, slop, or water-closet.

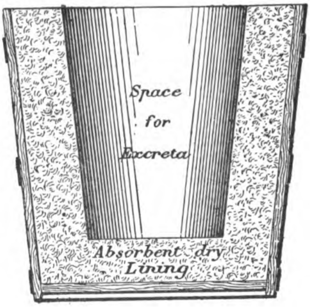
The **water-closet** is undoubtedly the most perfect method of removing the excreta from the house, but in some towns there may be a scarcity of water or the expense of connecting, and the rent to be paid for water is too great for the class of property; other systems have, therefore, had to be devised, which will, to some extent, remedy the evil of the wet-midden system.

115. The **pail system** is very simple. The closet is similar in size to that shown in Fig. 45, but the floor continues right through and under the seat. Usually it is placed with one wall in the back street, in which is placed a small door under the level of the seat. This door may be opened from the street, and the pail, which is placed under the seat, may be removed without in any way interfering with the household arrangements. The pail is a galvanised iron bucket of a capacity to hold a week's refuse from the average house. The pails should be removed at least every seven days, cleaned with a flush of water, deodorised and disinfected, and then exposed to the air for twelve hours before being used again. When the pails are being removed to the place of disposal they are, during such removal, covered with a galvanised iron cover fitted with india-rubber rings, so that neither the contents nor the foul air may escape. Fig. 46 shows the type of pail and cover here described. Fig. 47 shows the Goux pail, round the sides of which is a lining of an absorbent character, the space left in the centre is for the refuse; the liquid entering the pail is at once absorbed into the lining.



Pail with water-tight cover made from barrels Similar pails are made in galvanised iron.

Fig. 46.—Water-tight pail.

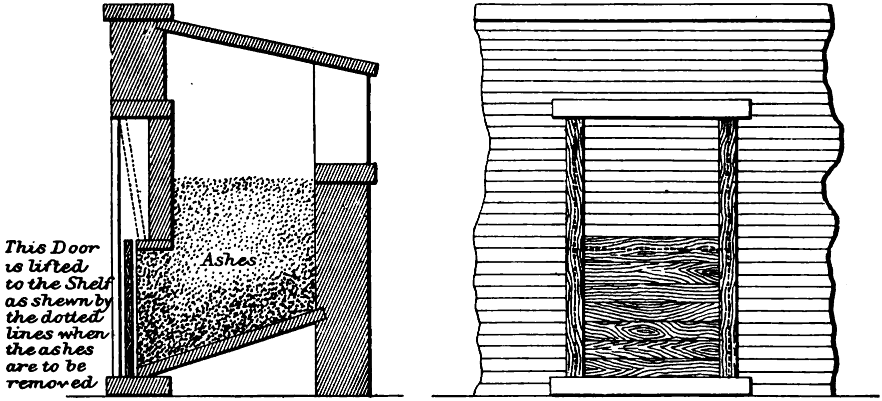


GOUX PAILS

Fig. 47.—Goux pails.

The excreta from pails is sometimes sold after being mixed with ashes, and in some towns a fair revenue is thus obtained, or it may be destroyed in a refuse destructor.

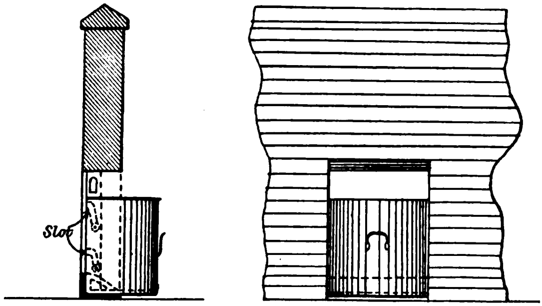
116. The objections to the pail closet are that no amount of washing will keep the sides and bottom perfectly clean; a thick crust is formed, and usually gives off an offensive smell. Sir Robert Rawlinson has said they are a filthy, stinking abomination,



SECTION

ELEVATION TO BACK STREET

Fig. 48.—Howson's ashpit door.

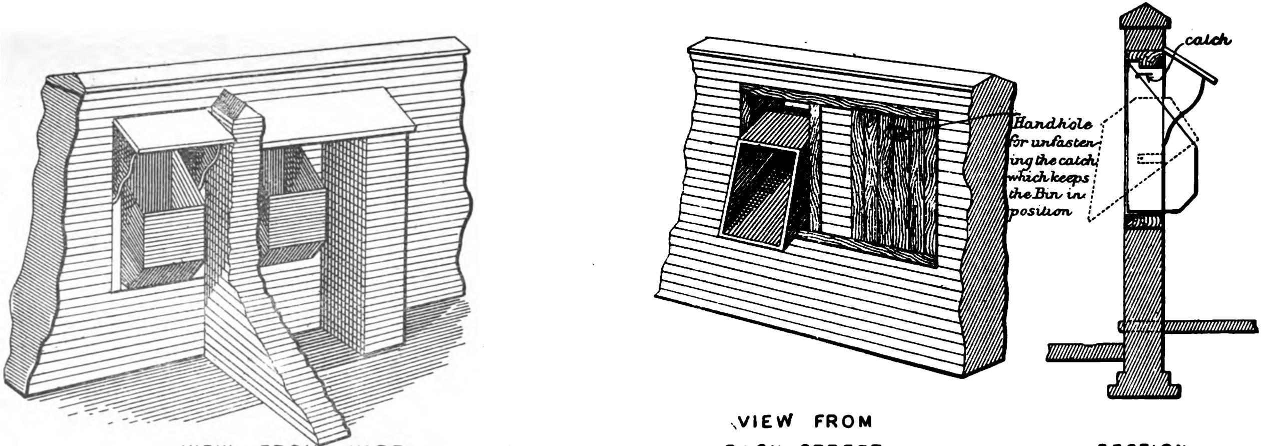


SECTION.

ELEVATION TO YARD

BRODIE'S PATENT ASH BIN.
(used at Liverpool)
These Bins are lifted vertically about 6 inches along the slots shewn and drawn into the Back Street.

Fig. 49.—Brodie's ash bin.



VIEW FROM YARD.

VIEW FROM BACK STREET.

SECTION

Fig. 50.—Dr. Quine's ash bin.

and this is not a too strong condemnation. Where there are large families more pails are used. There are many cases where the tenants of houses insist on pouring slop water into them, and by such procedure cause the liquid to overflow into the yard. It is such cases which render the system faulty. They require constant supervision in such cases as described, and also to ensure proper and sufficient attention to their cleanliness at the depôt. The cost of collecting pails and disposing of the refuse at the depôt is about 2½d. per pail per week. The system is one that in some towns cannot be avoided, as in scattered districts. The midden system is, of course, the cheaper (but is worse from a sanitary point of view), because they are not emptied more often than twice or three times a year. Where the town has an ample supply of water and a good system of sewerage and sewage disposal works, neither middens nor pail closets should be used, but in their stead the water-carriage system which is more sanitary and less expensive. The dimensions of a sewerage system would not be reduced by wet middens or pail closets being used in place of water closets and the cost of disposal of the sewage in the sewers would not be materially, if at all, decreased. The Rivers Pollution Commission in 1868 found that the sewage of a dry-closeted town differs very slightly indeed from that of a water-closeted town.

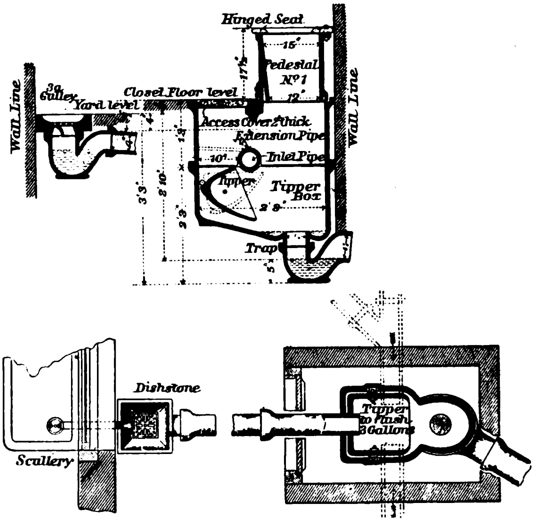


Fig. 51.—Duckett's automatic B slop-water closet.

117. Adjoining the pail closet is a covered-in and ventilated space which is for the receptacle or tub for receiving the week's

ashes and garbage of the house. Figs. 48 and 49 show designs for the ashes place or bin which are used in some towns. Fig. 50 shows Dr. Quine's system of ash bin. The latter two designs are very simple and take up very little room, but all are made so that they may be emptied into the back streets without inconveniencing the tenants of the houses to which they are attached.

118. **The Slop-water carriage system.**—In some towns there may be a good supply of water, but not sufficient to, in the opinion of the authorities, supply water-closets in such a manner as is generally used. It has been necessary to devise some scheme whereby the excreta may be discharged into the sewers and the water for flushing purposes be obtained both from the waste pipes of sinks and baths and from the rainwater pipes.

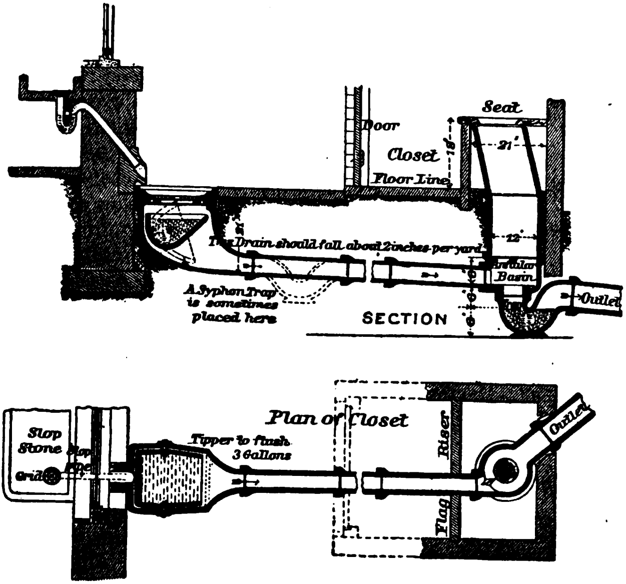


Fig. 52.—Duckett's automatic A slop-water closet.

These waste waters are run into a basin which is so balanced that when it is full it tips over and discharges the liquid into the pan or syphon trap of the closet and so flushes the excreta into the sewers. The basin for one closet usually holds about 3 gallons. The basin or tipper may be placed in any position desired, but it must discharge above the syphon trap. The most usual practice is to place the tipping chamber as near the seat as possible, as in Fig. 51; where desired, the chamber may be placed at some distance from the closet, as in Fig. 52. The closet may be very much reduced in size, as shown by Fig. 53, where the size is little different from that of the ordinary water-closet; in this case the closet must adjoin the scullery or room in which the sink may be placed. Fig. 54 is still another form of closet; here the excreta and liquids are held in the tipper until the latter is filled and tips its contents into the trap. Fig. 55 differs mainly in its being more movable or less cumbrous than that shown in Fig. 51, and that the discharge of the excreta is direct into the trap and has not an annular water space around the edge of the trap unless so desired. The whole construction is of the best salt-glazed earthenware.

119. It will be noticed that the chambers are very deep and, consequently, there is a very large area which has to be kept clean from the splashing which must occur in these closets; further, it must be remembered, it is not clean water that is used to flush the closet, but water from sinks which is already greasy and dirty. The sides must retain some of the excreta and refuse just as an enamelled water-closet does; in the latter the filth is seen at once and cleansed, but in the slop-water closets it may never be attended to. The tipper at times will, through some defect, cease to work, and if the householder is careless and does not look after his sanitary appliances, the power of the flush is reduced to an inconsiderable item, a point which would at once be observed in a flush cistern if that should be out of order. With this type of closet it is impossible to tell whether it is acting or not until the trap is choked, in three of the four cases shown, without removing the access cover. These accidents with the tipper are not by any means a frequent occurrence, but this state of affairs is probable. The tipper, in any case, requires constant supervision. The quantity of water required seems to be inadequate, especially if the system is adopted for those classes of cottages where very little water is used for cleaning purposes, except once in the week. Then, again, there are many cases where the householder thinks the closet is not properly cleaned out and the water tap in the

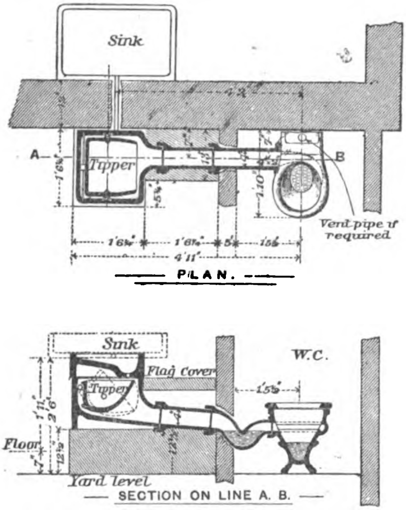


Fig. 53.—Duckett's rapid slop-water closet.

sink is allowed to run, in order that the tipper may the more frequently act. There is thus a waste of water. If the syphon could be seen to be working and the quantity of water properly regulated in each case, then the town would be gainers in one sense, as the amount of water dealt with would be less than that in the water-closet system and the sewage works would, consequently, be so much less in size. But as a matter of fact the sewage in such a system is stronger and might render the treatment very much more difficult; indeed it has been found to be more costly than in the system where pure water, a purifier in itself, is used for flushing purposes. It is cheaper than the water-carriage system; there are rarely any difficulties in frosty weather arising from the tipper or its contents being frozen, and, for this reason alone, many owners of property prefer it to the water-closet in backyards. This is perhaps only a minor reason for its adoption, the main one being the initial expense of the water-closet and fittings and the annual payment that has to be made for water. Corporations would find it beneficial to either lower their water charges for water-closets or do away with them altogether. The waste-water closet system is better than the pail system only in a similar proportion as the pail closet is better than the midden.

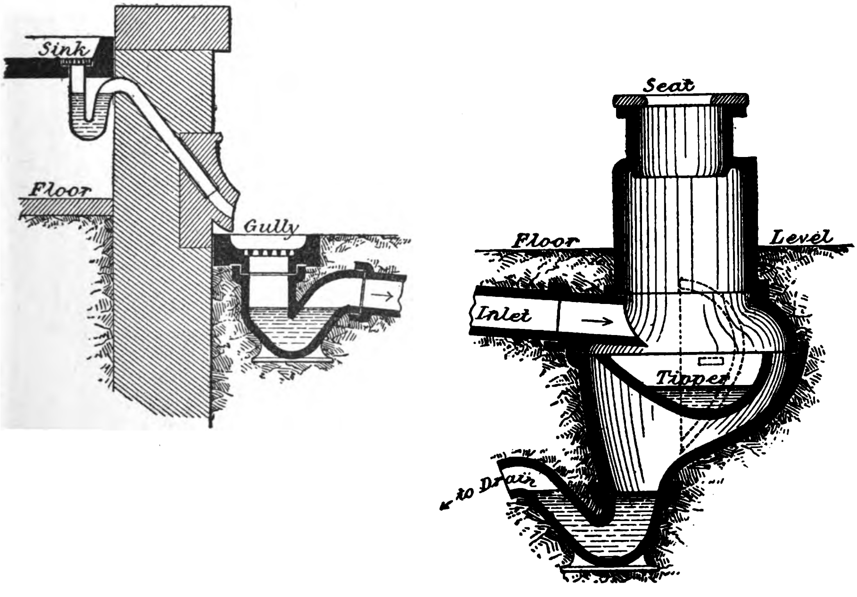


Fig. 54.—Day's patent Stafford waste-water closet.

120. Trough closets with automatic flush are used in factories, schools, and workshops; the amount of water used in this system is one of the objections, but this may be remedied. Fig. 56 shows another system of waste water closet, but modified for use with the trough system. It will be observed here that the tipper is discharged in the opposite direction to those in the other closets of a similar class; it is questionable whether there is any advantage, as

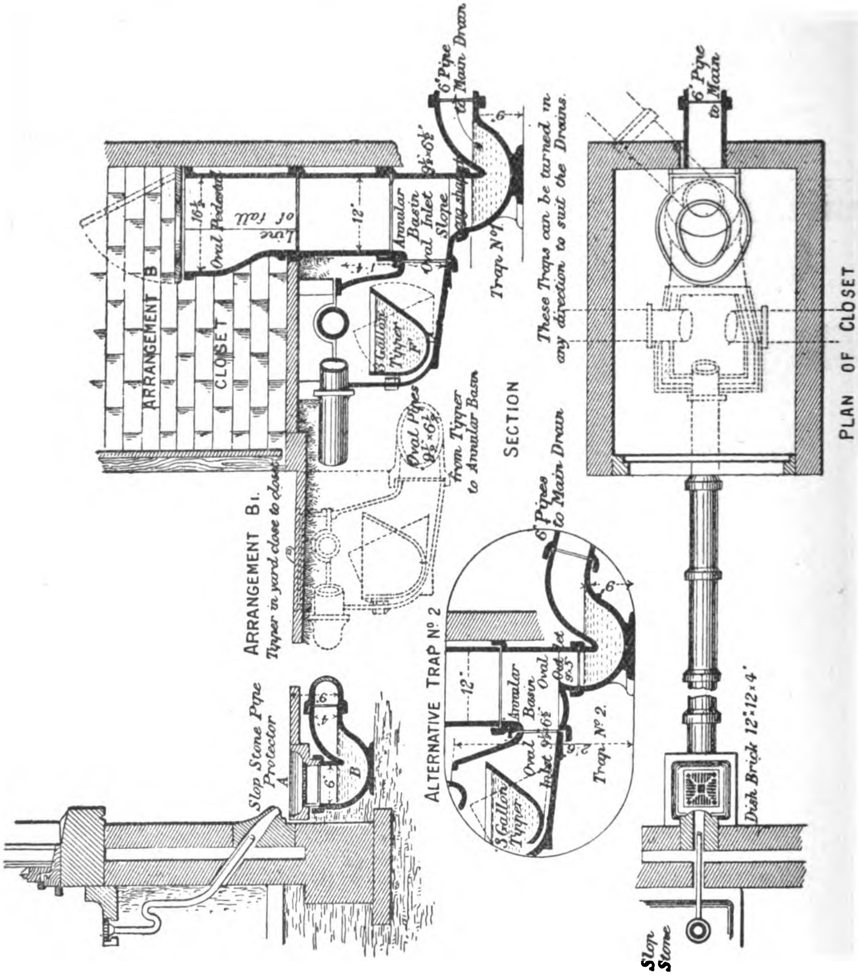


Fig. 55.—Whitaker's patent self-acting waste-water closet.

the water is by this means distributed over a large surface before it reaches the closet, and must, therefore, lose some of its force. Fig. 57 gives another illustration of the trough waste-water closet;

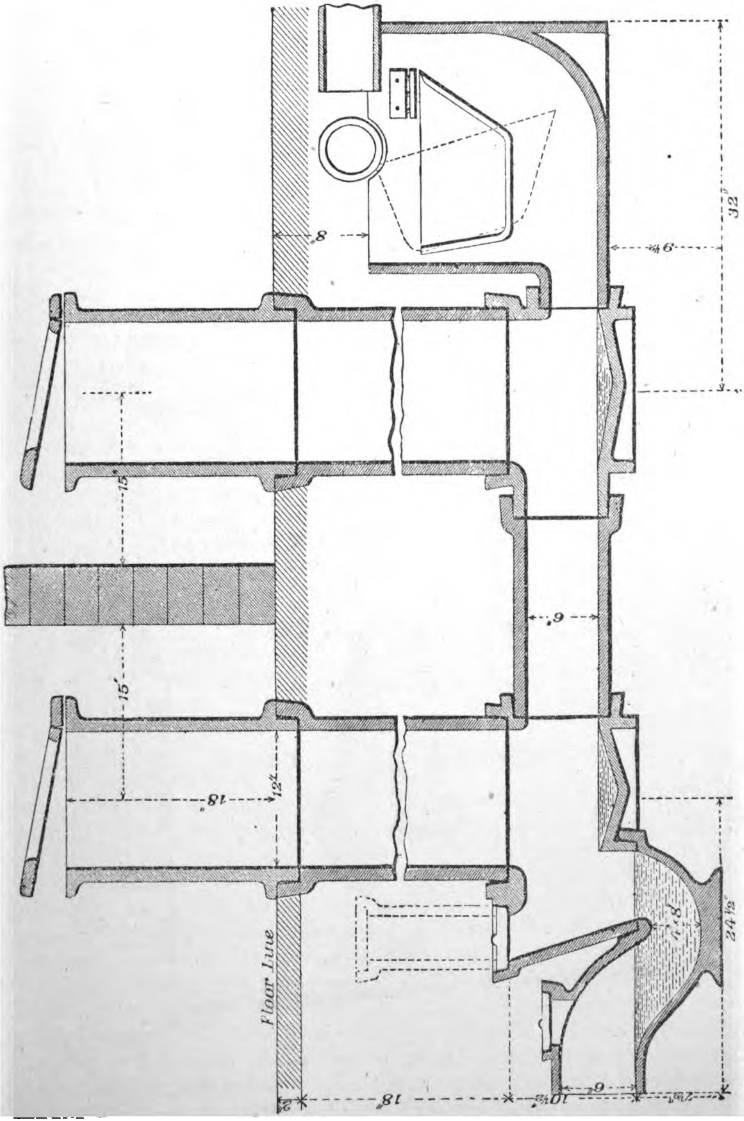


Fig. 56.—Oates and Green's closet.

here there is always a trough of water about 2 inches deep to hold the fæces. Fig. 58 shows the closet described in an earlier paragraph as adapted to the trough closet system.

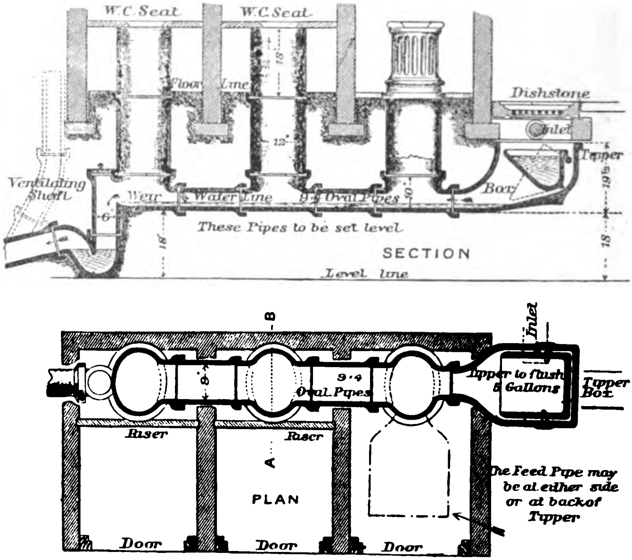


Fig. 57.—Trough closet.

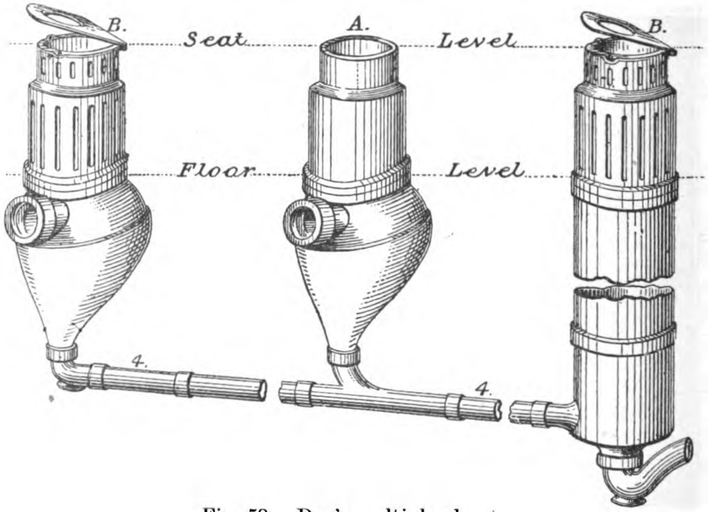


Fig. 58.—Day's multiple closet.

121. **Water Closet System.**—A very important part in the drainage of a house is the water-closet arrangement. In past years, the kind of closet known as the Pan closet was very much in vogue, but these are now being abolished, and closets with skilfully designed traps are replacing them. Fig. 59 shows the section of an old-fashioned closet with "D" trap; these traps had vertical sides, and, as shown in the sketch, they contained a large body of water; the segmental section of A, immediately under the hopper, was in the shape of a saucer; when closed, the edges of the hopper dipped into the water which the saucer contained, but, when opened as shown, it allowed the foul gas from the D trap to have free access into the chamber in which the closet was situated. The sides of the trap were always found to be coated with sewage or sewage growth, and from this the foulest gases emanated, endangering the health of all who used the same. They contained about 4 pints of water, whereas the accepted quantity for a trap with a 4-inch outlet should not exceed 1½ pints.

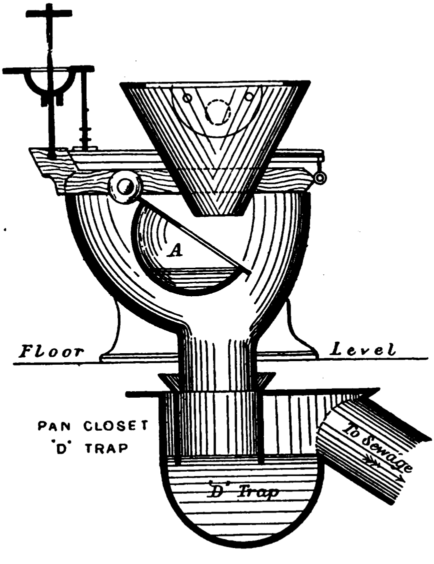


Fig. 59.—Pan closet; D trap.

122. Traps and syphons of every description should be made without angles; every part should be rounded off, and the material should be of the very best enamelled substance; if possible, it should be one to which excreta will not adhere and generate noxious gases.

123. Many improvements have been made, both in the design of the basin and in the trap of water closets, to which no objection can be made from a sanitary point of view. The two inconveniences are initial expense and damage by frost. In the winter, if the closet is not carefully attended to, the water in the trap may freeze, so that occasionally the trap is broken by the expansion of the water to form ice. The cistern which supplies the water may at this period of the year have its water frozen and be rendered useless. The cistern should be encased with wood, and the space between the wood-casing and the ironwork should be filled with

straw, felt, or sawdust. The trap of the closet should also be similarly treated, in order to lessen the liability of the water contained in the trap to become frozen.

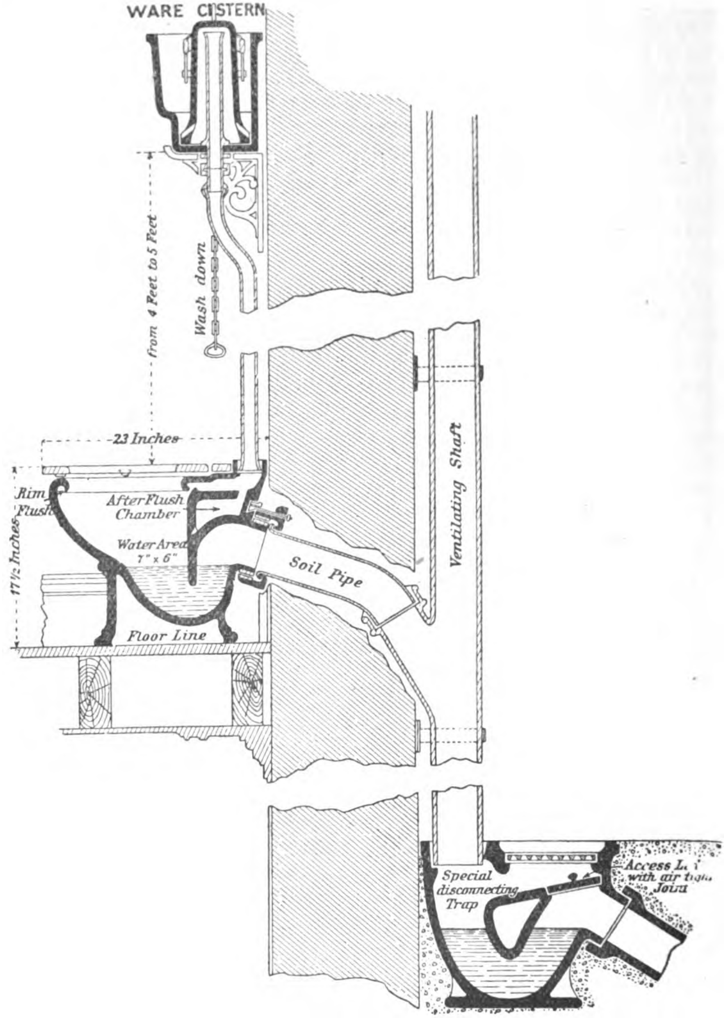


Fig. 60.—Wash-down closet.

124. The water closet should be so designed that the excreta fall directly into water, and become immediately immersed, the

depth being sufficient to prevent adhesion to the sides and the consequent breaking up of the excrement; the area of water should be such as will prevent the fæces from splashing the sides to any appreciable degree. The depth from the top of the basin to the surface of the water should be as shallow as can be made in order that the water may receive the fæces quietly; the seal of the syphon should be at least 1½ inches, but 3 inches is more usually found in practice. The entrance to the syphon should be as easy as possible in order to facilitate the escape of the water, and the outlet of the same should be made as quick as practicable to allow the contents of the trap to go to the drain without any return after the flush-out has taken place. The body of the trap should also be made as small as practicable—1½ pints for a 4-inch outlet and 2 pints for a 6-inch outlet being the capacities recommended. The rear of the basin should be set further back than the vertical line from the side of the opening immediately above.

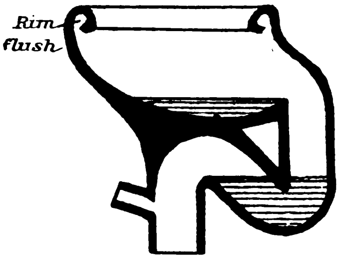


Fig. 61.—Wash-out closet.

125. Fig. 60 shows the whole of the fittings of a water closet of what is known as the "wash-down" type. Fig. 61 shows the "wash-out" type of closet, which is not so effective or cleanly as the "wash-down." Fig. 62 is of the type known as the "valve closet"; the valve seating is shown at the thick black line across the cylinder directly under the handle. By lifting the handle the valve also is lifted, and the mass of water, with its contents, escapes into the drain; when the handle is let down it touches the lever of a valve on the water main, thereby allowing water to run direct into

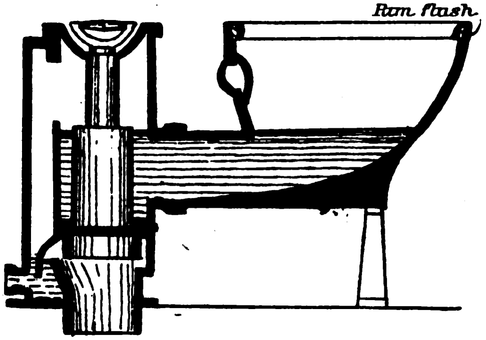


Fig. 62.—Valve closet.

the basin; it automatically shuts itself off; there is no cistern, and consequently there can be no frost difficulties except in the trap. The objections to this form of closet are that when the handle is lifted it must be lifted to its full extent, otherwise there is a difficulty in getting rid of the solid matter, and the clean water for filling the pan is not turned on. The valve on the water main sometimes causes trouble and inconvenience by not working properly. All working parts of a closet should be simple and effective; they should be of such a character that any plumber may immediately rectify them should they get out of order. The parts of a valve closet are of a special character, and if anything goes wrong only the makers can put them right. A later form of closet, and one that is very effective in its action is the "Syphon" water closet. As will be seen by examining Fig. 63, it answers all the

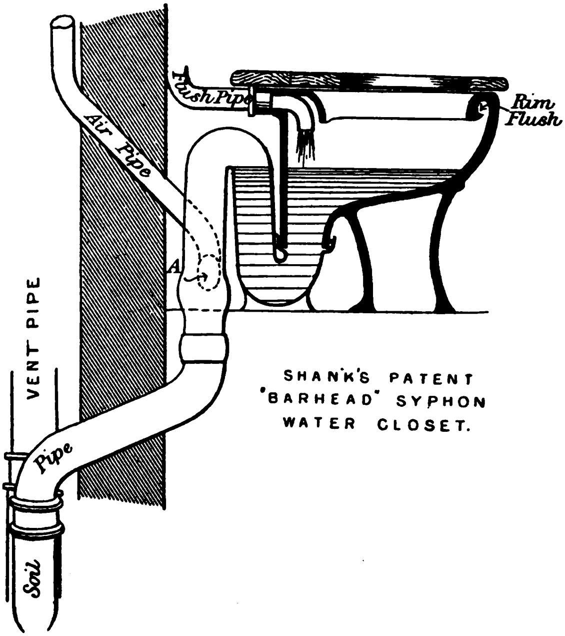


Fig. 63.—Shank's patent syphon closet.

itions of a water closet as set forth in Art. 124. The quantity
r in the closet trap is more than specified in Art. 121;
ype a syphon would not act with so small a quantity.
124. The w neer will have little difficulty in choosing the most
fall directly in of closet by examining any that may be brought
the lines indicated in the preceding articles.

126. In all cases the outlet pipe of the closet should have a vent pipe attached to prevent the trap being unsyphoned, as is explained in Art. 112 relating to the syphons on sink waste pipes. This vent would be placed between the points in the outlet pipe corresponding to A and F in Fig. 19, Art. 51. This is more important in a position where a series of W.C.'s occur on several floors immediately above one another, and all draining into the same soil pipe—*e.g.*, suppose, as there might be in an hotel, a series of five or six W.C.'s above one another, and at the top storey a person emptied a pail of slops into the basin of the water closet. The sudden flush would cause a very great displacement of air in the soil pipe, which would find relief in the weakest point—namely, the trap of one of the lowest W.C.'s in the series. It has sometimes forced the water in the lowest W.C. completely out of the basin; in the W.C. in the centre of the series the air has been drawn from the pipe connecting the W.C. to the soil pipe, caused a vacuum, and unsyphoned the trap in one of the others. All this would have been prevented by vent pipes, as above indicated. This vent pipe should not be placed in the apex of the syphon, but should be, as shown in Fig. 63, at a sharp angle with the pipe vertically.

The soil pipe ventilator should be at least 4 inches in diameter, increasing in size with the number of closets and anti-syphonic pipes connected with it to a maximum diameter of 6 inches.

127. Some sanitarians insist that a trap should be placed immediately below the soil pipe with a vent in the surface of the ground, the trap being a modification of, or similar to, that shown in Fig. 60. The vertical soil pipe is carried above the roof. The author fails to see the utility of the trap. If the W.C. is rarely used, the water in this trap evaporates, and then it ceases to be a trap; if the trap in the W.C. becomes dry through evaporation, so also will this one. In the winter, being so close to the surface, the water freezes and prevents the excrementitious matter and liquid from entering the sewer, so that it is then discharged through the grating on to the surface. This remark may, of course, be also said of gullies, but the matter which would collect in soil pipes is much more foul, and consequently more dangerous to the public health. They should therefore have greater facilities for the escape of the liquid into the sewer. There is this advantage in having an open grating at the foot of the soil pipe—it prevents, to a certain extent, a vacuum being formed by a large body of water rushing down the drain; it also forms a sort of cushion, and lessens the velocity down the drain. Should a trap be so placed, the surface of the water should be at least 3 feet below the surface of the ground; these are, in the author's opinion, only minor advantages, and in reality only apply to a situation where there may be a great height of soil pipe above the ground floor, as in hotels. If an intercepting trap be provided at the junction of all the drains

before it enters the main sewer, it answers the purpose just as well as placing a trap in the position indicated. Hence, given a good gradient for the drains and subsidiary sewers, so as to ensure the rapid escape of the sewage, there need be no fear as to any foul gas penetrating into the dwelling houses or habitable establishment to which they may have been attached.

128. **Traps** lose their seal through "syphonage," "momentum" (as described in Arts. 112, 126, and 127), or through "evaporation." The wind blowing down a soil-pipe ventilator has been known to unsyphon a trap.

Lead traps for sink wastes should have a seal of 1½ inches at least. The body of the trap should be narrower than the inlet, especially when used in such positions as under sinks. This concentrates the water and assists in giving the trap a good flush when the water is poured into it. Fig. 64 shows a trap of this character. When the water is discharged, it should be delivered vertically on to the water standing in the trap.

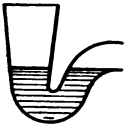


Fig. 64.—Trap with large outlet and small inlet.

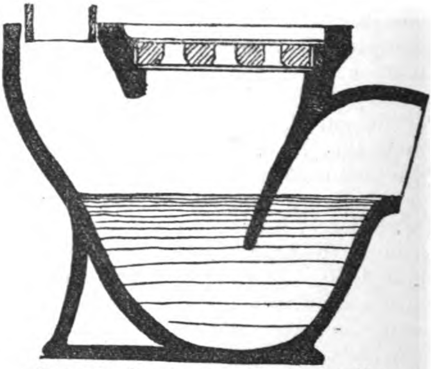


Fig. 65.—Duckett's rain-water gully.

Carmichael and Wernech, at the Philosophical Society of Glasgow, said :—"Water traps are, for the purpose for which they are employed (*i.e.*, for the exclusion from houses of injurious substances contained in the soil-pipe), perfectly trustworthy. They exclude the soil-pipe atmosphere to such an extent that what escapes through the water is so little in amount and so purified by filtration as to be perfectly harmless, and they exclude all germs and particles, including, without doubt, the specific germs or contagia of disease, which we have already seen are, so far as known, distinctly particulate."

Fig. 65 shows the trap that may be fixed to a rain-water downspout. Figs. 66, 67, and 68 are traps which are used at the foot of soil-pipes; the surface of the water in the traps ought to be about 3 feet below the surface of the ground to prevent the freezing of the water in cold weather (Art. 127).

129. Wherever water runs, so also will hot grease and oil, but

these matters are not so easily dealt with as water in either sewers or sewage works. They should, therefore, be run into what are known as "grease traps," of which Fig. 69 shows a specimen. In these traps the grease cools, and may be taken out and boiled in order to remove all water; it may then be used for many economical purposes. The quantity of sand and grease from a single house is surprising, and, if not thus collected, the grease goes into the drains and sewers and cools there, and in a sewer with a sluggish fall it coagulates and has frequently caused stop-

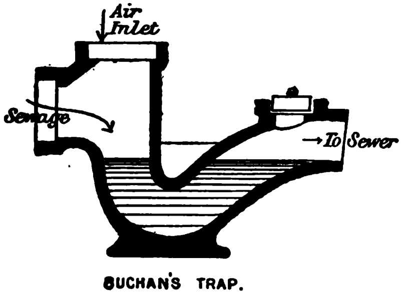


Fig. 66.—Buchan's trap.

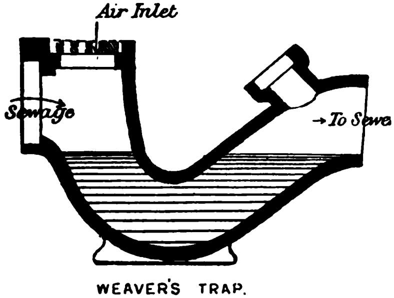


Fig. 67.—Weaver's trap.

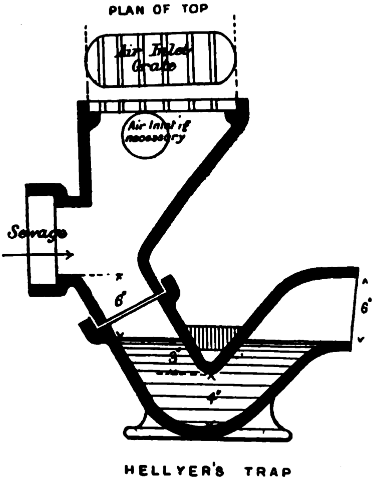


Fig. 68.—Hellyer's trap.

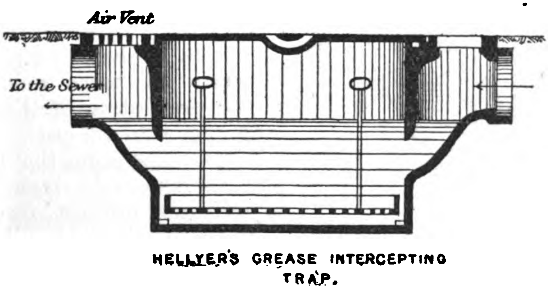


Fig. 69.—Hellyer's grease trap.

pages. Hotels and manufactories now recognise the value of the grease and collect it for its commercial value.

130. If an intercepting trap be placed on a house connection, then the house side of the trap should have an air-shaft or chamber with an open grating in order that the gases generated by the substance standing in the trap should be diluted; it will then, at times, act as a down-draught with the soil-pipe as an upcast. Such a trap should hold, for a 6-inch outlet, no more than 6 pints of water, and for other sizes in proportion. These traps are commented on in Art. 173.

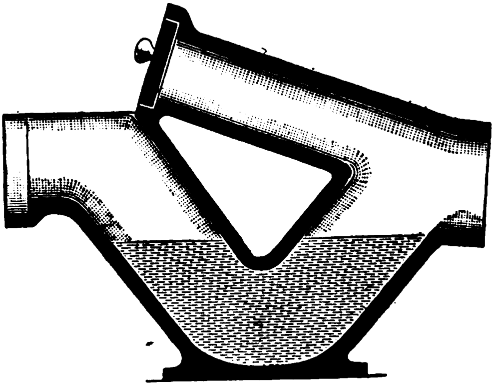


Fig. 70.—Interceptor trap.

Fig. 70 shows a form of interceptor trap with cleaning eye. Figs. 71, 72, and 73 show respectively Q, S, and P traps, which are sometimes required when making house connections. Figs. 74 and 75 show two traps which serve the same purpose, viz., the prevention of the reflux of sewage into a house.

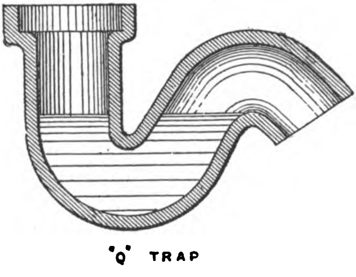


Fig. 71.—"Q" trap.

131. The notes that have been made respecting traps for W.C.'s, sinks, and interceptors also apply to the traps of gullies, which should be formed of good glazed material; the openings of the gratings should not be too small—that is, the size should be similar to those in Fig. 55—and the grate should not be too easily removed (*i.e.*, be movable only with an effort), in order that the trap may not be unsyphoned by the sudden inrush of liquid from large vessels, or blocked by large masses entering the gully.

Gullies for the removal of surface water from the streets are made with a catchpit of large holding capacity. Some have pits which would contain about 5 cubic feet of detritus (coming from the washing of the road by the storm). They are made either of earthenware or of cast iron. Those made of cast iron have an inner box which catches the refuse and which may be lifted out and immediately emptied into a cart; the detritus in the other cases are scooped out. Where large bodies of water may be anticipated, the bars of the grating are oval-shaped with the nose pointing sideways. The gratings are very strong to withstand the traffic. The seal of the trap is at least 3 inches. The size of the grating varies up to 24″ × 15″.

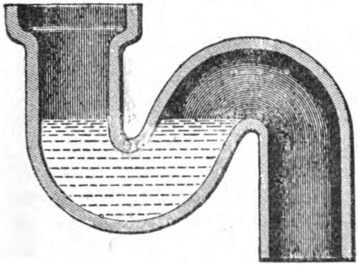


Fig. 72.—" S " trap.

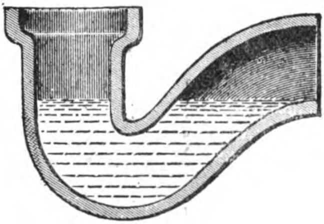


Fig. 73.—" P " trap.

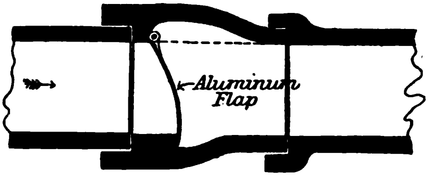


Fig. 74.—Flood preventer.

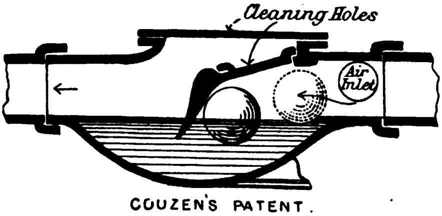


Fig. 75.—Flood preventer.

CHAPTER VII.

LAND DRAINAGE.

132. The contour features of the land are the results of the co-operation of a large number of agents which destroy the coherency of the materials on the steeper slopes and more exposed surfaces, and remove the waste products from the higher to the lower areas and from thence into the sea. Locally, and in limited areas, the changes are quite perceptible within very short periods of time, but, so far as the general landscape is concerned, scarcely any change can be detected by ordinary observers from one generation to another. The constant changes of volume are due to fluctuations of temperature hourly, daily, and seasonally; the solvent and chemical actions of air and water; the disintegrating actions of ice, water, impact of materials, growing plants, and movements of animals—each and all lend their aid in various degrees in reducing the larger fragments to smaller ones; while rain and rivers, currents of air, glaciers, snow-slides, earth-slides, animal and mechanical locomotion, and oceanic waves and currents combine in carrying the detritus towards or into the open sea. The rate at which the general operation proceeds depends mainly on the rate of reduction to the smaller particles, together with that at which these are carried from the land by the currents in the ocean. The great bulk of the work is effected by the agents which act with the greatest constancy, but with low intensity; but the most striking effects are the result of agents acting with the greatest intensity for brief periods of time over a relatively small area.

In countries like the British Isles almost every surface is exposed to rain, which washes off the smaller particles that are constantly accumulating during the dry intervals; the rain collects into runlets, and streams, and rivers, which at first increase in force and pick up larger fragments, shaping the drainage lines as they flow and fashioning the river basin. In the higher districts, mountains, hills, and ravines are carved out; lower down the features become less rugged, while nearer the sea the features are less sharply defined owing to the less intense denudation and the smoothing effects of the deposition of the materials which the stream is unable to carry. In the aggregate the amount of deposition corresponds to that of denudation, the degree of ruggedness being in proportion to the preponderance of the latter operation, while the broad plains are correlated with the preponderance of the former.

The rate of denudation varies very much according to the locality, and even in the large river basins. In the Mississippi river basin the mean is about 1 foot in 4800 years; in the Tay it is about 1 foot in 1842 years, and in the Thames basin 1 foot in 11,740 years. A fair general average is 1 foot in 7200 years. This corresponds to the removal of 1 cubic foot of material from the land by 300,000 cubic feet of rain-water. Occasionally the rate is very much larger than usual. For instance, a waterspout recently caused great damage to one of the railways in Derbyshire. Even under ordinary conditions large deposits are formed very quickly. The river Mersey, for example, carries down daily large masses of sand, which is deposited some seven miles from the mouth of the river, forming a "bar." The Mersey Docks and Harbour Board have employed specially-designed sand pumps to remove the obstruction, which has, until recently, necessitated vessels anchoring outside during low tide. It has been computed that the river Thames carries down 548,320 tons of detritus every year, of which two-thirds is carbonate of lime. The rivers of England carry in suspension about 8½ million tons of material every year, a statement which may be more clearly grasped by saying that the whole surface of England is lowered by subaërial denudation 1 foot in 13,000 years.

133. Rivers flow in a course through a valley bordered by an easily-defined line of mountains, hills, or ridges, which form the watershed of the river or its tributaries. In cross-section the river at certain points may be deep and narrow and in the form of a cañon, or very shallow and wide, or between these limits. The wider the valley the slower will be the velocity of the river, and, as a river decreases in velocity, the less will be its power of erosion, and the less also will be its power of carrying deposits from the higher reaches; as a consequence it leaves the detritus obtained from the sides and bed of the river or from the hillsides at places where its velocity is decreased. In Art. 64 is given a table which shows the rate of velocity required for removing certain sizes or weights of material.

This process of deposition continues through ages until an embankment or terrace is formed to such a height that the floods are unable to reach it. The flood water is then confined to narrow limits, its velocity increases, and the terrace formed in this valley is eaten away and carried to still lower reaches. It is rarely that the terrace is wholly washed away, and in many places a succession of terraces, one above the other, is distinctly observable. In all flat low-lying valleys a deep bed of gravel or alluvial deposit will be found; the author in one place found the deposit to be 35 feet in depth. Trial holes will show that the river has flowed in all parts of the valley; these former beds have become filled with sediment from floods, glaciers, or rivers.

134. The process of evaporation is also taking place daily. The humidity of the atmosphere varies in different towns and lands in proportion to the surface of water in the river passing through the lands or in the land and earth itself. Evaporation is not to be seen, but one frequently feels the atmosphere to be damp, although there may be not the slightest sign of rain or mist. The heat of a summer in Africa or Australia is not felt so much because the atmosphere is dry, but in England a similar summer temperature would be felt to be oppressive and enervating, which is accounted for by the greater humidity of the air. The effects of evaporation may be seen on a river at night, especially in the late summer; the river gives its moisture to the air, which is unobservable in the day time, because the sun heats the air above its water-holding capacity; at night time the earth, which, during the day, has also been heated by the sun's rays, cools down quickly, and the temperature of the air falls consequent on the withdrawal of the sun's influence and its contact with the cooler earth; the atmosphere is then not capable of holding so much moisture, which falls in the form of a mist. If the subsoil water sinks below 5 feet from the surface, the atmosphere is unable to derive any moisture from it, and the site is suitable for dwelling-houses; if such water rises nearer the surface, the site is too damp for healthy occupation.

135. There are various methods of lowering the water to such a depth as to have little effect on the health of persons living on this land.

Generally speaking, clay in some form is to be found near to the surface in these low-lying lands; there may, however, be little or none there. Sand will also be near to the surface, and this, changing to gravel, may continue for any depth up to 40 feet or more. At the lowest depth will be found large boulder stones.

The summer level of the river will be 8 or 9 feet below the general contour of the neighbouring land; but the level of the sub-soil water will be nearer to the surface than this, if the sub-soil water drains from the land into the river. A thorough system of land drainage will alone lower the depth of the water.

If the top layer should be clay or clayey material, this material should not be cut through to enable the water to come above it, rather the drainage should take all that is above the impervious earth, and whatever water there might be below should remain.

In America, on an estate near to the Niagara Falls, the water has been lowered some 4 or 5 feet by systematic land drainage and pumping. This land from being a swamp is now laid out in streets, houses have been built, the population is rapidly increasing, and what was known as a death trap is now a healthy and prosperous town.

All inlets into the river or stream by means of a gravel bed connection must be stopped, otherwise the attempt to drain the land will be futile when the river is in flood, which may occur very frequently and at times for a prolonged period. Only known outlets should be allowed, and these should be provided with tidal valves or sluices.

If there is no proper system of drainage and the lowland near the river is formed of gravel or other pervious material, the ground water may rise a little nearer to the surface when the river is in flood, not, of course, in the same proportion, and sink almost as rapidly as the flood subsides; this, of course, depends upon both the capacity and efficiency of the drains which have been laid.

136. If there is a stratum of clay above the river bed, the bank of the river may be walled, or a puddle trench may be put in so as to prevent the water from backing into the land. The walling must be impervious to water, and it would act as a training wall if carefully designed; by such a work much land might be reclaimed which had been previously swept by floods. It is a costly process, and, unless there was a prospect of commercial gain, would rarely be carried out.

To avoid floods in Holland, the dwellings are built on piles driven into the sand; this would not answer the purpose we have been seeking, unless the sands were also raised.

Another method may be adopted with success—by raising the road level to a height which would leave the water 8 or 9 feet below its surface, the site of the buildings and lands would then be covered with damp-proof material—*e.g.*, concrete. Here the moisture is not able to penetrate the concrete, and, being so far below the surface of the road, the atmosphere would be healthy.

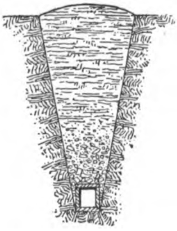
In this case an embankment would have to be made round the edge of the river to the level of the highest known flood, because no drainage would be provided to remove the water. This is, however, a desirable construction in every case.

137. The cause of many floods in rivers is in the fact that weirs have been placed in various positions for canalisation or for supplying manufactories with water power or for condensing purposes.

Should these weirs be detrimental to the interests of a town, they ought to be removed or altered in design. The cost of such a proceeding would be very large, as the riparian owners would have to be compensated, sometimes it means the construction of a new canal. At Leicester a very comprehensive flood scheme was carried out at a cost of half-a-million sterling, but the enhanced value of the land and the great and lasting benefits to the population has quite repaid the Corporation for their enormous expenditure. The scheme included the straightening of the River Soar, the removing of old and constructing new weirs, the providing of a wider and deeper channel for the canal, and a new course for the river. The basis of calculation was a rainfall of 1⅜ inches in 24 hours.

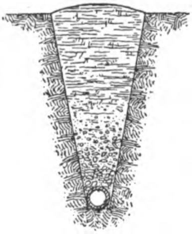
Land is always very valuable at a river or canal edge, especially for manufacturers, as they are not only able to obtain water, but they also have in the canal a cheap conveyor of their goods.

138. Figs. 76 to 79 show the various methods employed in draining land. The land tiles in Fig. 77 are of earthenware, 3 to 4 inches in diameter; they are laid butt jointed, and covered with stones so as to allow the water to run into the pipes through the joints without taking with it any small material which might choke the pipe; they are laid about 6 feet below the ground level, with a fall of about 1 in 150. The rate of flow through the ground will vary up to about 10 gallons per square yard in 24 hours. They are usually about 66 feet apart (the distance of the drains apart from each other depends greatly on the nature of the sub-soil), and not in longer lengths than 200 feet before they join a larger and collecting main running in a different direction; a 4-inch drain will just discharge at the rate of 10 gallons per square yard per hour, if laid at an inclination of 1 in 150. In a land drainage system there are placed in convenient positions sumph wells or chambers (Fig. 80) for collecting the sediment which may get into the drains. The walls of the chamber are built with rough stone without mortar, so that the sub-soil water in the land round about may have free access; if the water could not obtain access, and the inlet pipe should by some means be blocked, the land immediately round the chamber would subside, and if the chamber were placed near a wall or building these latter might be damaged by such subsidence.



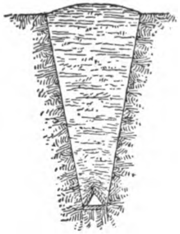
Rough Stone shaped Drain (Square) covered with stones.

Fig. 76.



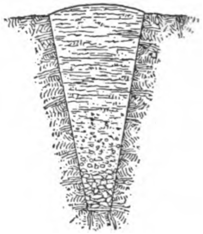
Field Drain Tyles covered with stones

Fig. 77.



Rough Stone shaped Drain (Triangular) covered with sods.

Fig. 78.



Rough Stone Drain. Large stone at bottom smaller as it gets higher, after the style of a filter bed.

Fig. 79.

139. These land drains could be, and often are, used as surface water drains—*i.e.*, for the rain water which may fall on the surface of the land. Should they be used for such purposes they would have to be greatly increased in size. The land built upon, the streets, &c., every parcel of land which could take water by a system of surface water drainage would be called the "built-up

area" or "rain-water area." Then provision should be made to take 50 per cent. of a rainfall of ½-inch in one hour over that surface. It has been found that if a given quantity of water fell in an hour on a given surface, it does not flow into the drains at the rate it falls, but at the rate of 50 per cent. of the fall in that time, the remaining 50 per cent. disappears in various ways, some of it finding its way into the sewer, and the rest is either absorbed by the earth or passes into the air by evaporation. If the land should be so built upon as to be termed suburban, only about 30 to 40 per cent. of it flows into the sewers within 24 hours of the storm.

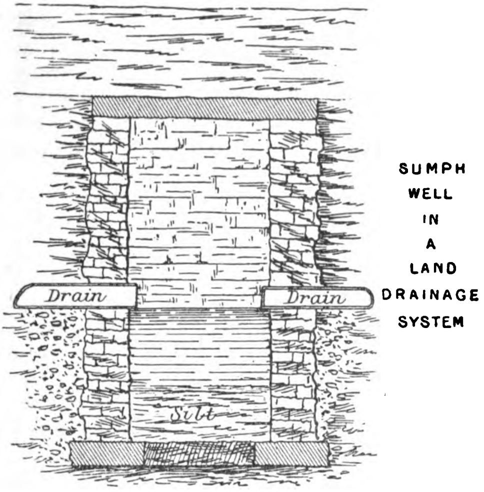


Fig. 80.—Sumph well.

CHAPTER VIII.

SEWERS.

140. IN towns that have been in existence many years (that is, towns which may be termed "old"), or in the old parts of a town, the scheme of sewerage is very primitive. The surveyor, or whoever may have designed the scheme, must have had peculiar ideas when determining the dimensions of the sewers. His first step probably, was to take the nearest and most direct line from the area he wished to drain to a water-course or river. He would also reason that a man could with no great inconvenience creep through a sewer if it were made about 3 feet high and 18 inches to 2 feet wide, and no matter what inclination, or what area had to be drained, the sewer would have to be of these dimensions. In his experience the author has found two sewers, each 3 feet 3 inches by 2 feet 2 inches, one on each side of the roadway, with an inclination of at least 1 in 100, and a drainage area of at most 30 acres.

If the earth through which the sewer passed was rock, the invert would be either flat or segmental in shape, roughly hewn out of the rock, the sides would be cut vertically, and a flag or rough stone placed over the top; in other cases, the sewer would be constructed of rough rubble work. Mortar, for such culverts as these, would rarely be used; indeed, no cases of such use have been met with in the author's experience. The evolution of the sewer is apparent in another case in the clean, self-faced flag for the invert, good brickwork for the vertical sides, and flags for the cover, the dimensions being still on the vague lines indicated. At a more scientific stage the invert is put in semicircular, and the top arched over, but the sides were still vertical. Afterwards the vertical sides were dispensed with, and mortar was used to close the joints. The author's experience in one other case which may be noticed was a brick sewer 2 feet in diameter to drain ten houses. When the sewer was broken into to find the cause of an obstruction, it was found to be three parts full of matter, into which an iron bar 5 feet long by 1¼ inch diameter was forced; so solid was the obstruction that the bar remained vertically standing.

141. The connections from the houses were invariably made in the top of the sewer. Immediately below many of these connections heaps of refuse could be seen, both above and below the point in the invert where the water had dropped.

The manholes that were constructed sometimes came to the surface and in other cases were covered over with a stone about 2 feet 6 inches below the surface. The manholes themselves were about 2 feet square, which is barely enough to allow a man to go down to the sewer. They were placed at no regular intervals; they seldom occurred at junctions with other sewers, and were not placed at changes of inclination; they were merely intended for cleaning purposes. Lampholes were never used; these, however, are now becoming obsolete in schemes of later date. Flushing chambers had not been thought of.

142. The system of cleaning the sewers was as primitive as the constructions. A man would creep through, removing the obstruction to the nearest manhole, where there would be a sumph or well to receive it; the sediment in the sumph would be lifted to the surface of the roadway at the time or at some more convenient period, and carted away. These sumphs, placed in most of the manholes, having a connection with the surface, would soon become full, and the stench from them was oftentimes abominable. Perhaps the reason why sumphs were constructed was to meet the complaints of persons about the deposit of offensive matter that would occur at the outlets into the river or watercourse. This deposit, no doubt, would be a serious nuisance, and the sumphs would be a remedy if they were regularly and properly attended to. They were about 12 inches deep and were very quickly filled; in this state they soon became a hindrance or impediment to the flow, which, sometimes acting as a small weir, dammed back the sewage until it gained power to sweep the obstruction into the next length of sewer, and passed into the watercourse or into some sewer with a flatter gradient. As the flow decreased in speed, the refuse would be deposited, and eventually this length would become choked.

These features in the history of sewers are now passing away, the mal-constructions are being removed, and properly-designed culverts and manholes are now being built in their stead.

143. The undermentioned matter, which affects the designing of sewers in new streets, may here appropriately be noticed, although some may consider it to be outside the scope of this work.

The sewerage system of a town is in the hands of the municipal authority; it belongs to them by right of the Public Health Act, 1875. In the general case a drain is a sewer (*i.e.*, it is repairable by the local authority) when two or more houses drain into it. This, of course, is subject to many modifications, dependent on the facts and circumstances of each case, which do not require notice here. It would seem, then, that the local authority should have the privilege, if they desire it, of actually designing and constructing all sewers proposed to be laid on new estates, as much saving and a better result would be obtained. The idea has been carried out in several places with great success. Architects, as a rule, have no special knowledge as to drainage matters, so that it is better that he should confine himself to laying out the estate from a commercial standpoint, and put the drainage operations into the hands of the competent civil engineer who is acting for the local authority. The author has, in many cases, suggested new routes for the sewers, better inclinations, altered the dimensions, given details of manholes and lampholes, corrected specifications, shown where flushing chambers should be placed, and given the position and level of the main sewer with which these sewers have to be connected. Oftentimes the plans have to be redrawn. Practically, the municipal engineer has designed the scheme in the interests of the local authority.

Information is also given in a similar manner for the construction of streets, but the local authority in general obtain the privilege of forming the streets under the 150th section of the Public Health Act already mentioned.

When the sewers are being laid out, the engineer to the local authority is expected to supervise the construction and pay as much attention to it as if it were entirely in his hands; the works get little attention from those who have laid out the scheme, and, as they are so much in the hands of a builder or perhaps a navvy who has suddenly become a contractor, the work is oftentimes covered in after only a cursory examination. The author has found these sewers laid with the fall in the wrong direction, as in the case of a flat district where it was imperative the sewer should have been very carefully and accurately laid. The local authority has the power to enforce the proper construction of the sewer, but an error of workmanship not seen during construction cannot be rectified afterwards. If the engineer had designed and carried out the works with his own men, then he might, with some reason, feel less anxious as to the accuracy of its construction.

144. With regard to the design of sewers and matters relating thereto, there is yet much scope for improvement, and, if more time could be devoted to the study by experiments, the present theories might be very greatly altered. The results that have now been attained are the outcome of great industry on the part of a multitude of engineers who are so deeply interested in a subject with so many possibilities.

There are many varieties of shapes of sewers, but only a few types. The design of the section of the sewer must be made to suit the conditions of its situation.

The main object of the design is to obtain for a certain quantity of water the least wetted perimeter. The quantity of water varies with every hour of the day, and with it the velocity will also alter, as will be proved later. This is especially the case in towns which have large manufactories which discharge their waste liquors at times most convenient to themselves. It may be dye water, greasy water, waste liquor from breweries, and, in some cases, water from condensing engines, which invariably contains grease and oil. Domestic refuse water is also variable; at sewage outlets the colour of the sewage alone will show how changeable is the quality of the liquid that has to be dealt with.

Some kinds of sewage will develop a fungoid growth; this more frequently occurs in sewers with a small velocity. This growth attaches itself to the joints of the pipes, and becomes a hindrance to the flow. In every sewer, even though the inclination and the material of which it is constructed may be similar, the velocity of the water will differ. Sewage with a density greater than water will have a slower progress; if grease or oil be a constituent it will be retarded more than if the sewage were free from it. The oily substance clings or adheres to the sides, causing greater friction, and reducing the capacity. Then the liquid may be principally dye water with little depositing matter, or it may carry a large amount of suspended matter. Water from woollen mills carries in suspension a fine and imperceptible fibre, which may collect and cause a stoppage. Gullies from yards of houses send into the sewers large quantities of both sand and grease; more especially do the gullies from streets deposit sand or fine dust, depending on whether it drains the surface of a macadam, gravel, or paved roadway. Any volume of liquid entering a sewer alters the density or specific gravity of the sewage in some degree.

Figs. 81 and 82 show diagrammatically the discharge of a large and small sewer in a manufacturing town during each hour of the day. The discharge from the large sewer ranges from 17,000 gallons to 126,000 gallons, the ratio being about 1 : 8. In the smaller sewer the ratio is 1 : 16. There is always a quantity of water flowing in a main sewer, and the minimum flow will bear approximately a fixed relation to the maximum flow in each town. The average daily flow has been obtained from many towns, and it has been found to approximate very closely to the rate of half the total volume per day flowing through the sewer in 6 hours. This average calculation is not always allowed for at this rate. The sewerage scheme for Leicester was calculated at the rate of 70 per cent. of the total volume flowing through the sewer in 8 hours.

A point to be observed in the diagrams is the time when the flow is greatest; evidently, in large and small sewers, there is being discharged other refuse than "domestic," and in the small sewer the subsoil water entering is inappreciable.

145. One of the most important points in the design of a sewer is the rate of flow of the liquid in the sewer. It has already been stated that the flow depends on the inclination, the volume of the liquid flowing in the culvert, and the wetted perimeter. The only fixed item is the inclination. If the volume varies, the wetted perimeter will also vary, not, however, in a similar proportion, as

will at once be seen. Conversely, the volume varies with the wetted perimeter. As we know that the volume does vary, we may therefore infer that the velocity of the sewage in a sewer having a given inclination is varying with the volume every hour of the day.

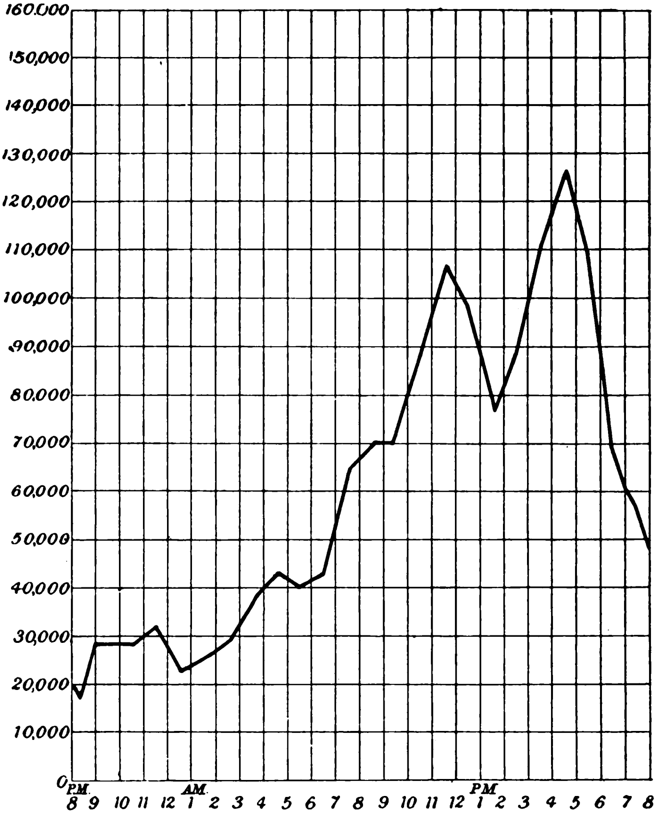


DIAGRAM SHOWING THE DISCHARGE OF A LARGE SEWER AT EACH HOUR OF ONE DAY. TOTAL DISCHARGE 1.540.000 GALLS

Fig. 81.—Discharge of large sewer.

The student, in examining the wetted perimeter and volume flowing in a circular sewer, will find that the maximum flow will be when the sewer is $\frac{7}{8}$ full; but a very near approximation to the maximum flow occurs when the sewer is half full or full; the rate diminishes as the volume decreases below half the capacity of the sewer.

If the sewerage is to be conducted on the "separate" system, in which the rain-water is led away from the surface by surface water drains, then the rate of flow should be the average flow when the sewer is half full. But if the sewer is to take both storm water and sewage liquid (or be on the "combined" system), then the sewage flow proper would bear but a small proportion to the area of the sewer. It is quite usual to allow for it in the proportion of 1 : 20 or

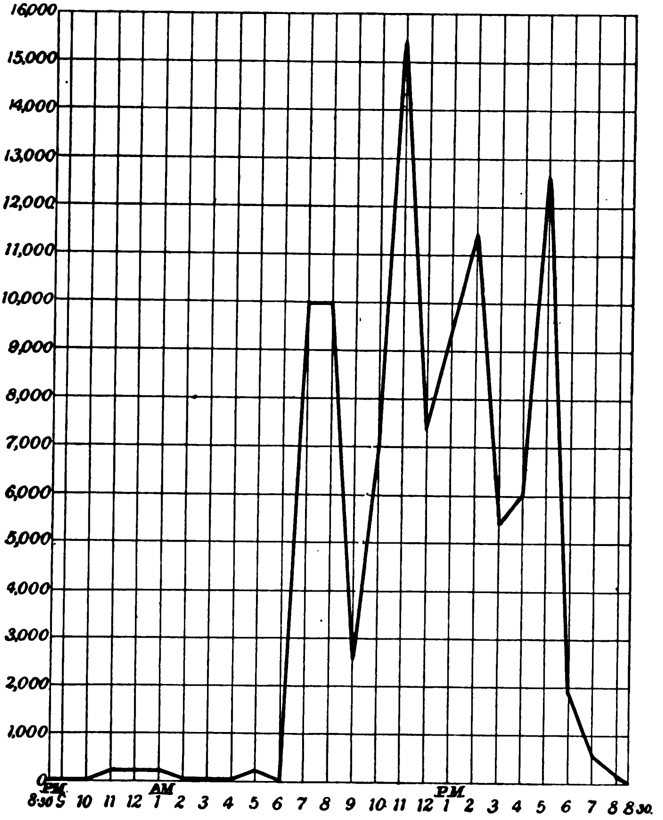


DIAGRAM SHOWING THE DISCHARGE OF A
SMALL SEWER DURING EACH HOUR OF ONE DAY.
TOTAL DISCHARGE 101472 GALLS

Fig. 82.—Discharge of small sewer.

25—*i.e.*, the sewer would be of sufficient capacity for 21 to 26 volumes of sewage, of which one would be sewage, and 20 to 25 volumes would be rain-water.

If the velocity of the sewer is taken when the sewer is half-full or full, this is misleading, for the sewage will in itself never attain to this velocity in the combined system.

An illustration will be given here for a sewer on the separate system. Given a sewer of 18 inches diameter; the inclination is 1 in 840; when this sewer is half full it has a velocity of 2 feet per second, and the discharge is at the rate of 108 cubic feet per minute. The maximum flow was, say, 216 cubic feet, and the minimum 28 cubic feet. Then at the minimum flow there would be only 4 inches on the invert, and a velocity of 1·48 feet per second. It must be apparent that if this sewer were on the combined system, and had to discharge sewage equal to $\frac{1}{20}$ of the maximum flow, the velocity for this small quantity would be very little.

146. It is this minimum flow which should have a self-cleansing velocity—that is, a velocity which will keep the sewer in which it is flowing in a good and clean condition. The velocity which is termed "self-cleansing" is not any fixed and definite rate. Most engineers agree that it should be between 2 feet and 3 feet per second. It should be that which will remove all reasonable obstructions from the sewer. The articles which find entrance into a sewer vary very considerably, but in most up-to-date systems they are confined to such as sand, gravel, and grease, because the gratings which cover all inlets into the sewers are small in sectional area, and catchpits, such as in gullies, are placed in convenient positions to intercept a probable inflow of larger material. The author in his experience has found on having certain drains examined (mostly from slop-water closets, which are with some people a convenient receptacle for rubbish) such articles as the head and legs of a fowl, dead kittens, scrubbing brushes, cotton waste, female underclothing, putrid meat, brush handles, and various other things. These are, however, generally confined to the drain between the closet and the sewer, and have to be removed at the expense of the owner. Occasionally they get into the sewer, and even a rate of 3 feet per second will not move them very far, if at all.

After referring to the conditions in the table in Art. 64, it would seem that in branch drains and sewers which have a small and intermittent volume of sewage flowing, a velocity of 2½ feet per second should be ensured for the minimum flow, such a velocity might be expected to remove any sand, gravel, and fæces obtaining access to the sewers. From the table one might infer that stones about 1½ inches diameter would be swept forward, but their removal depends greatly upon the volume flowing.

For larger sewers which have a constant flow, the velocity for the minimum flow might be reduced to 2 feet per second, which would remove all materials up to 1 inch diameter.

When the branch drains and sewers become half or two-thirds full from a heavy rainfall, which in this country occurs very frequently (see Art. 248, p. 179), the velocity would increase to about 3 feet per second, and in the case of the larger sewers to 2½ feet per second, which would wash away any larger material should it perchance have gained entrance.

It will be understood that this rate cannot always be maintained, but it is one that should always be kept in view.

In a gravitation scheme especially, the sewers cannot, in most cases, be brought to show this result; but where pumping is resorted to, very great improvements in the inclinations may be acquired. If the latter method is adopted in a scheme, the advantage thus gained is a sanitary advantage, not one that can be appreciated in a monetary sense; still it must be put against the cost of pumping as a very decided advantage.

147. It has already been stated that in times past the branch sewers were connected with the main in the summit of the arch. This practice should always be condemned. To illustrate the effect of water being dropped vertically into a sewer:—Take a bowl of water, allow it to become perfectly quiescent, pour a quantity of water through an upright funnel until the bowl is quite full. No lateral movement in the water can be observed during the course of this experiment. Next arrange an inclined channel tangentially to the edge of a bowl containing water; pour water down the channel, and there will be seen a distinct movement in the water; it will turn round the centre with a velocity increasing with the velocity of the water running through the channel.

Junctions with mains should be so placed that the water will enter the sewer as nearly as possible in the direction of the flow, so as to assist the flow and not hinder it. The inlet should be placed just below the level of the average flow of the sewage in the sewer.

148. At whatever speed the sewage enters the sewer, it will settle down to the velocity which its inclination or coefficient of friction will allow. If water enters a pipe without any velocity of approach, as, for example, in the case where the water is quiescent in a tank and the entrance to the pipe is partly under and partly out of the water, it will travel a considerable distance down the pipe before it attains the velocity which has been obtained by calculation from a formula.

The loss of head in attaining the calculated velocity is—

$$h = \frac{v^2}{2g} = 0{\cdot}0155\, v^2.$$

For example (in Fig. 21), let A C be the side of a tank, and A B be a pipe 9 inches in diameter, and having an inclination of 1 in 240. It is required to find the distance the water would travel before it obtains the velocity which would be given by calculation from the formula in Art. 58, the surface of the water in the tank being quiescent, and lowered until it just covers half the inlet to the pipe at A.

$$v = 124\ \sqrt[3]{\cdot 1875}\ \sqrt{\tfrac{1}{240}} = 2\cdot 62 \text{ feet per second.}$$

The head lost in attaining this velocity is—

$$\begin{aligned} h = 0\cdot 01550\, v^2 &= 0\cdot 0155 \times (2\cdot 62)^2 \\ &= 0\cdot 1065 \text{ feet,} \end{aligned}$$

and as the inclination is 1 in 240, the distance traversed would be 25·56 feet, at which point the velocity would be at the rate of 2·62 feet per second.

Sewage invariably enters a sewer with a velocity of approach, but if this velocity is not equal to the calculated velocity for the sewer, it will be seen that the sewage will have to travel some distance before that speed is reached.

It is, therefore, desirable that the inclination of all branch drains or sewers into a main sewer, especially one with a small inclination, should be such as would give the calculated velocity for the sewer into which it enters.

149. Circular earthenware pipes, from 4 to 24 inches in diameter, are commonly used for the construction of drains and sewers; generally the smaller pipes are 2 feet long, and the larger—viz., 18 inches to 24 inches—are from 2 feet 6 inches to 3 feet long. The earthen material of the pipes below 12 inches diameter is about $\frac{3}{4}$ inch thick, those larger than 12 inches are $\frac{1}{10}$ the diameter of the pipes in thickness. 24-inch pipes are costly, more so than a 24-inch diameter brick sewer with $4\frac{1}{2}$-inch brickwork. It is not, however, good policy to construct a 24-inch sewer with $4\frac{1}{2}$-inch brickwork on any but a firm foundation; a 24-inch pipe sewer is cheaper than a 24-inch sewer with 9-inch brickwork. The pipes of this dimension have such a thickness of material that it is very difficult to burn it properly, and pipes not well burnt, if subjected to a continual and varying flow of sewage, will give way and crack, especially on exposure to the weather. The cracks allow the subsoil water to enter the sewer. The author had occasion to take out several hundred yards of pipes of this size; the pipes either fell to pieces on being taken out, or did so when they came to the surface; the material was black throughout the whole thickness. There are some firms of pipe manufacturers who have a class of fireclay which enables them to thoroughly burn a 24-inch pipe. There are, however, few who do it with success. All pipes require very careful handling while they are being laid, and this applies specially to those of large dimensions.

There are also egg-shaped pipes, to the larger sizes of which the objection given above also applies, but there are sizes—such as 16 inches by 10 inches, 21 inches by 14 inches—which are objectionable on account of the radius of the invert being very small, the narrowness of the foundation, and the consequent subsidence of the pipes; the sewer, in place of being in one continuous line, is broken-jointed and undulating, and therefore liable to stoppages. In a rock foundation, if carefully laid, they would be reliable, but in a yielding foundation, which for an ordinary pipe sewer might be considered firm, the base should be widened or supported by concrete.

150. The object of the egg-shaped sewer is to gain for those sewers in which the sewage is small in bulk at certain periods of the day a greater velocity by the increased head and a smaller wetted perimeter than the circular sewer of equal area. When, however, the quantity increases in volume, the wetted surface becomes equal to that in the circular sewer, and, when full, the wetted perimeter is greater in the oval sewer than in the circular sewer of the same capacity. For small quantities, up to about one-quarter full, there is a decided advantage in having oval-shaped sewers.

	Egg-shaped Sewer.		Circular Sewer.
	Old Form.	New Form.	
Area, when full, . .	1·148 d^2	1·106 d^2	0·7854 d^2
„ „ $\frac{2}{3}$ „ . .	0·756 d^2	0·713 d^2	0·5499 d^2
„ „ $\frac{1}{3}$ „ . .	0·284 d^2	0·278 d^2	0·226 d^2
Perimeter, „ „ . .	3·97 d	3·92 d	3·1416 d
„ „ $\frac{2}{3}$ „ . .	2·39 d	2·35 d	1·89 d
„ „ $\frac{1}{3}$ „ . .	1·375 d	1·45 d	1·227 d
H.M.D., „ „ . .	0·29 d	0·285 d	0·25 d
„ „ $\frac{2}{3}$ „ . .	0·315 d	0·307 d	0·29 d
„ „ $\frac{1}{3}$ „ . .	0·206 d	0·192 d	0·185 d

d being the greatest width of the sewer.

Figs. 83 to 89 show different forms of sewers. Fig. 83 is the circular sewer (1 to 1), Fig. 84 is the old form of egg-shaped sewer (2 to 3), Fig. 86 is the new form of egg-shaped sewer (2 to 3), and Fig. 85 shows another form of sewer which is sometimes built; there are many others that have been constructed as the different situations call for them. Figs. 87, 88, and 89 show these three forms of sewer with the area equal to that of the circular type (Fig. 83). The amount of water shown in each section is equal in every case. In Figs. 87 and 88 the wetted perimeter is equal to that of Fig. 83 for that volume of water; but in Fig. 85 it is rather more (about 5 per cent.). Fig. 90 is still another type of sewer used in

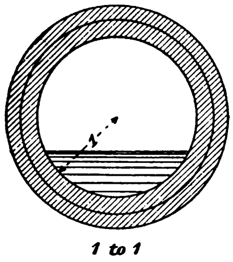


Fig. 83.—Circular (1 to 1) sewer.

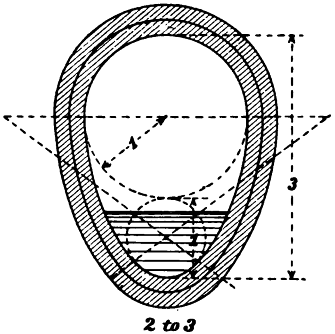


Fig. 84.—Egg-shaped (2 to 3) sewer.

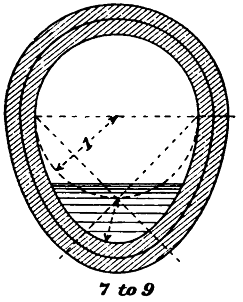


Fig. 85.—Egg-shaped (7 to 9) sewer.

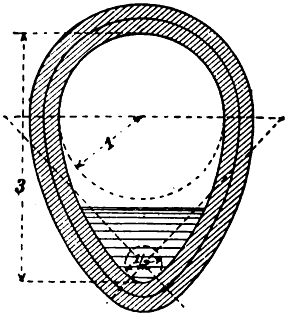
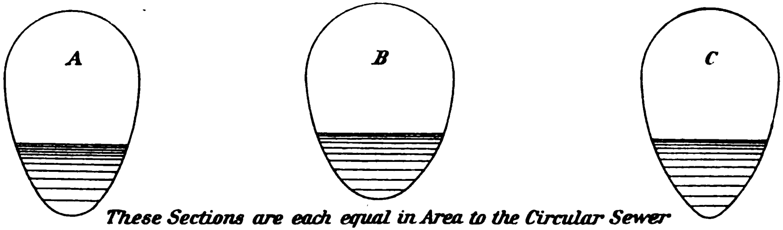


Fig. 86.—Egg-shaped sewer.



These Sections are each equal in Area to the Circular Sewer
The Area shaded as Water is equal in every case

Figs. 87-89.—Egg-shaped sewers.

large towns; the ordinary flow is in the portion below the landings, the larger area is for the water in times of flood. In such culverts as these, gas and water mains have been proposed to be laid, if it is not actually done in some cases; it is a dangerous course to

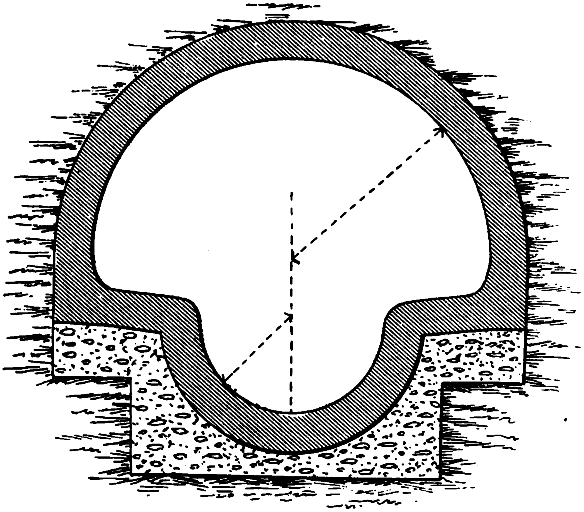


Fig. 90.—Sewer for large towns.

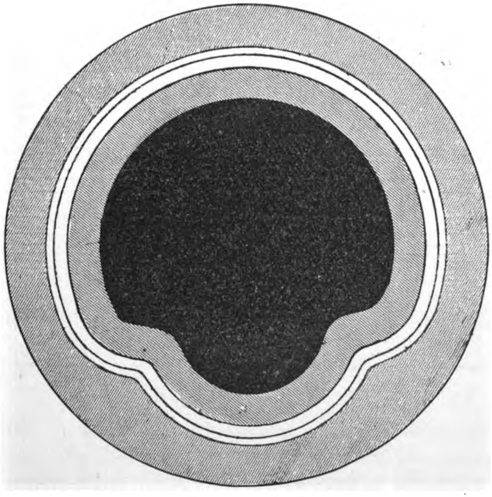


Fig. 91.—Plummer's drain pipe.

adopt on account of the probable escape, especially of gas, which would, of course, ignite and cause an explosion should a naked light be taken into the sewer for any purpose.

Fig. 91 shows a drain pipe which has been designed for small sewers, and is to serve the same purpose as that shown in Fig. 90.

151. It has been the object of many persons to improve and render watertight the joints of sewers. Figs. 92 to 98 show the various joints which have been used in many places. Fig. 92 was one of the first to be used; the dark portion of the section is a composition which is put on the socket and spigot of the

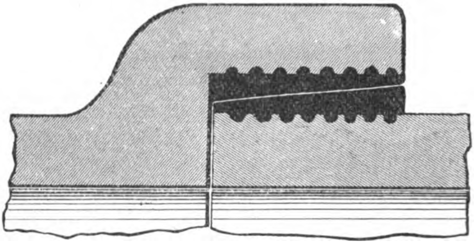


Fig. 92.—Stanford's joint.

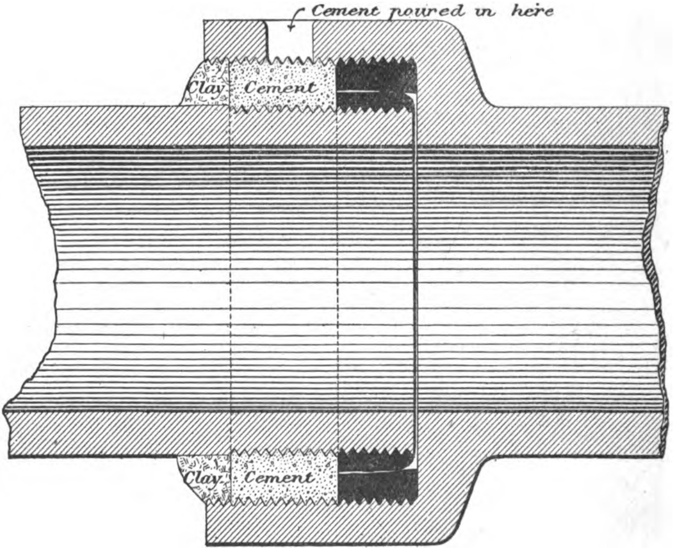


Fig. 93.—Hassall's single-lined joint.

pipe after it has been burned—the composition is wiped over with oil before the spigot is placed in the socket, then it is rammed home, and, the oil having softened the composition, the composition of both spigot and socket adheres and makes a solid joint.

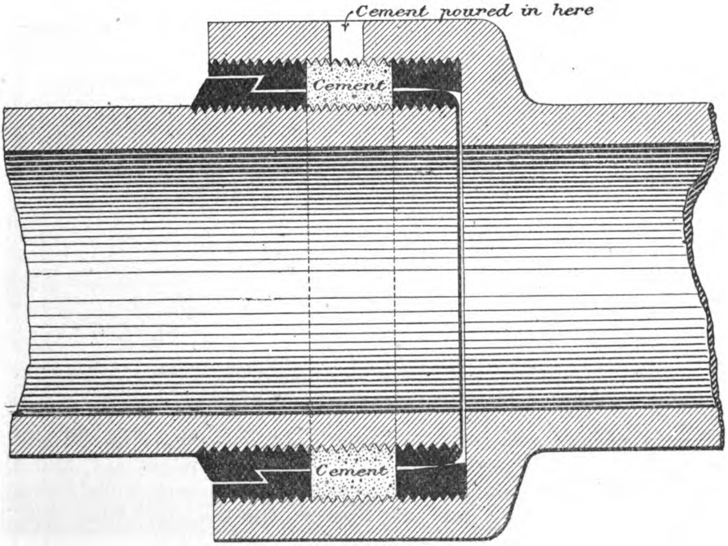


Fig. 94.—Hassall's double-lined joint.

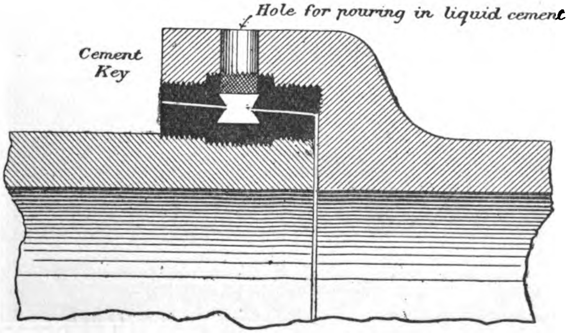
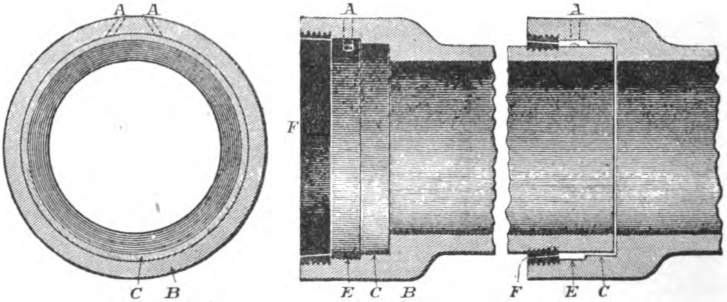


Fig. 95.—Button's patent secure joint.

Fig. 93 shows a similar joint, but clay is placed on the outer edge and cement in a liquid form is run in between the composition and the clay. In Figs. 94 and 95 composition takes the place of the clay. Fig. 96 shows another form; A A are the holes for pouring in the cement, B is a strengthened and lengthened socket, C is an inner socket and rest, E is a chamber for the cement, and F is a Stanford joint similar to Fig. 92. Fig. 97 is a form of joint in which clay is placed in the angles A and B and round the circumference, the projection A B C is pushed home, and the clay takes the form shown by the dark portion. The remaining space is filled in with liquid cement through the hole D. Fig. 98 shows a joint; the dark portion indicates the clay or cement, and the dotted portion shows the cement which has been poured through the openings. There are two lips on the socket which are to preserve the alignment of the pipes.



CROSS AND LONGITUDINAL SECTIONS.

Fig. 96.—Oates and Green's joint.

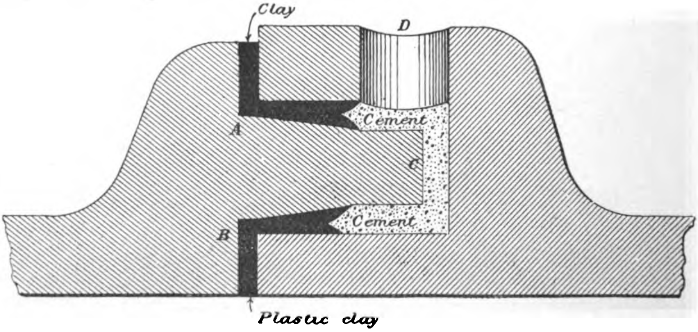
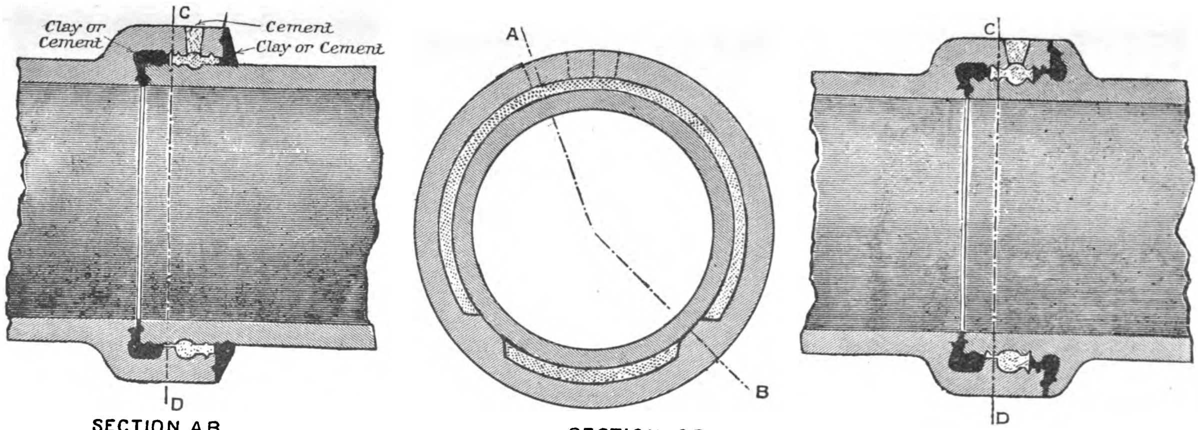


Fig. 97.—Archer's patent joint.

Fig. 100 shows still another form of joint; the pipes are laid in the same way as the ordinary pipe is; there are, however, curved lips to support the spigot and thus form a true line on the invert of the pipe; clay is placed round the pipes, and holes are put in the socket in order that liquid cement may be poured in to complete the joint.



SECTION .A.B
SINGLE SEAL

SECTION .C.D.

SECTION .A.B.
DOUBLE SEAL

Fig. 98.—Ames and Crosta's joint.

It may be thought that clay puddle properly filled in the joint would keep the drains watertight, but it is not found to act

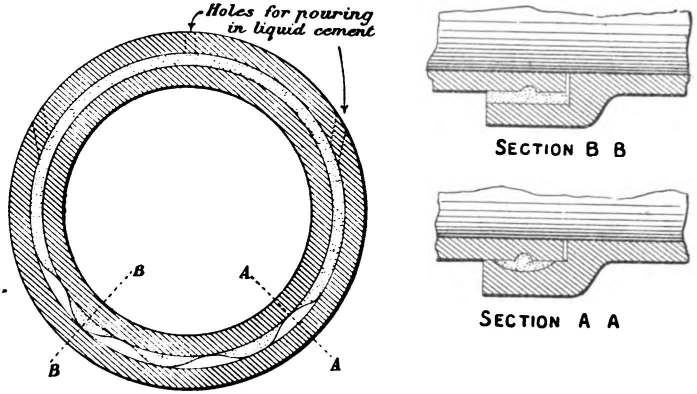
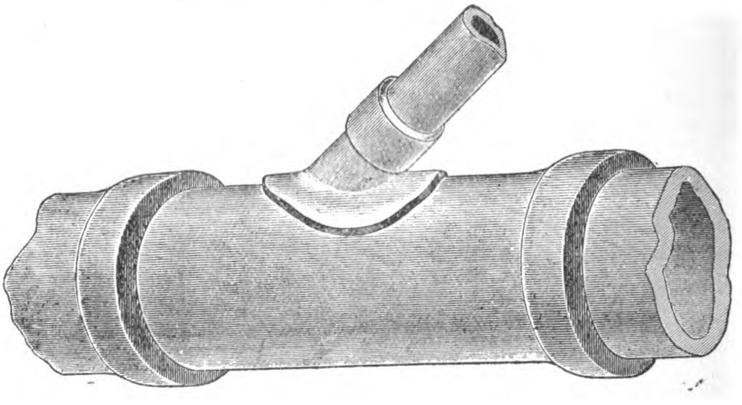


Fig. 99.—Wakefield's patent joint.



SLANT SADDLE JUNCTION AS FIXED IN MAIN DRAIN.

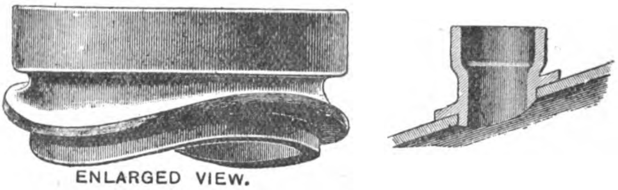


Fig. 100.—Oates and Green's slant saddle.

efficiently; the flow of water in the pipes soon washes away the clay, and, leaving a hole, allows subsoil water to enter. When clay is used, the foundation should be lowered 6 inches, then filled with clay puddle, and when the pipes are laid they should be surrounded with it to a depth of 6 inches—after the joint has been made. Otherwise cement should always be used in the proportion of one part of cement to two parts of sand.

152. When a branch drain is intended to be put into the main and a proper junction has not been provided, some engineers take out several yards of pipes, replace one of them with a junction, and spring the pipes into position; such a proceeding is not to be recommended; it is costly, and its supervision would tax the ingenuity of most ordinary inspectors. A skilled workman will drill a hole, which will take the form of an ellipse, in the side of the pipe; this hole will be for the reception of a saddle junction (Fig. 100). The pipe drain would make an angle with the main equal to at most 60°. Figs. 101 and 102, A and B, show a similar form of junction-block that is built in a brick sewer. Figs. 101 C and 102 C show the block which is built in the brick sewer for a lamphole.

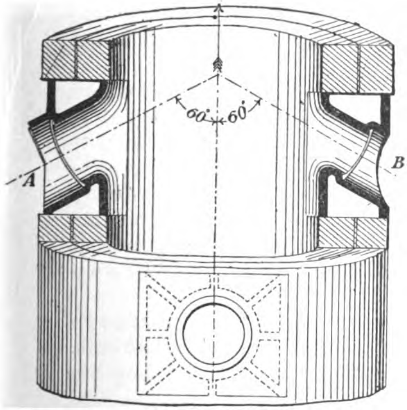


Fig. 101.—Plan of sewer with blocks.

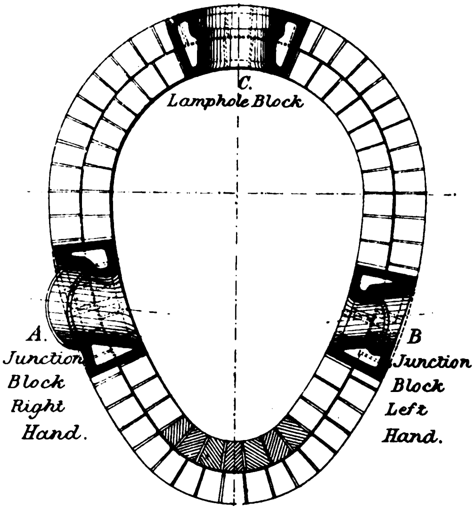


Fig. 102.—Section of sewer with blocks.

CHAPTER IX.

SEPARATE SYSTEM.

153. THE question of laying down a system of separate drainage is one which requires very careful consideration. By "separate system," we mean that a drain is laid to take off all the sewage and foul liquids, and that another system is laid to take away all rain and surface waters.

The Private Street Works Act, 1892, if adopted by a local authority, enables that authority to enforce owners of private streets to lay down separate drains for sewage and for rain water respectively.

The expense of chemically treating a quantity of sewage which has been diluted to, say, three times its bulk by pure rain water, is more expensive than treating one volume of sewage—*i.e.*, it takes a considerably greater quantity of chemicals to precipitate this matter in the increased bulk of rain water. This is probably due to the sewage impinging with or permeating the whole volume of the mixture, so that the chemicals have to be greatly augmented in quantity in order to come in contact with the more widely disseminated material.

There may, however, be other and more legitimate reasons in that, when a rain storm falls, the first washings from the streets, houses, yards, &c., are very foul. It has been stated that they are much worse than the sewage in the sewer, and therefore should not be allowed to enter either river or stream. That these washings are foul may be easily conceived; if the weather has been fine the roads have, where there is considerable horse traffic, a large amount of horse manure in the joints of the setts or in the macadam, which has not been brushed away, but which is easily washed into the sewer by a rain storm. A rainfall, when it enters the sewer, flushes the sides and joints, and gathers up a quantity of foul matter. Both contribute in no small degree to render the sewage more difficult to deal with at the disposal works.

At the same time, there must be taken into consideration the quality of sewage to be dealt with at the disposal works. It will be seen from Art. 119, that the sewage from a system where slop water-closets are in vogue is difficult to deal with unless it be considerably diluted. It is desirable that rain water should be mixed with such a sewage, especially in a system where chemicals are used at the outlet works.

It is an acknowledged fact that rain water oxidises the sewage, and therefore greatly helps in the purification of the sewage, and this paragraph, in conjunction with that on p. 104, may seem in contradiction; it is not so, however, in reality, for the sewage may be slightly oxidised, yet not enough so to render the treatment at the works less expensive when it arrives there. Rain water also keeps the sewers in a comparatively pure condition, whereas on the separate system the sewers would have to be flushed by artificial means; and this must be done very often if the sewers are very flat and have not a self-cleansing velocity for the average flow. In the separate system it is highly desirable that the sewers should have a self-cleansing flow.

154. For this system, the area of the land required for treatment purposes would be decreased, tank capacity would be lessened, pumping expenses would also be lowered if it involved a pumping scheme, as the quantity to be lifted would be comparatively constant. All the sewers would be small, and all the surface water drains, however large they might be, would be very shallow.

The cost of construction of a separate system would in many, if not most, cases be cheaper than a combined system.

In small towns, the sewage being small, the sewers would also have to be small, and unless the inclinations were good, it would seem as if the combined system should be adopted in order to keep water in the sewers, and also to free them from obstruction.

In old towns the sewers are shallow, not above 4 or 5 feet below the surface of the road; these sewers could easily be converted into surface water drains after being properly cleaned out, and the house drains disconnected from them.

155. The above conclusions do not point to a satisfactory condition if a separate system be adopted in its entirety; they suggest a scheme which should be a compromise between the separate system and the combined system.

The advantages of the separate system may be enumerated as follows:—

(1) Treatment at outfall works less expensive.
(2) Quantity of water in sewer approximately constant for each individual hour in each day.
(3) Less precipitating tank area.
(4) Less filtration area.
(5) Sewers and surface-water drains cheaper to construct than the combined sewer system.
(6) No flooding of cellars.

The disadvantages are—

(1) Sewage would be too strong.
(2) Flushing arrangements are required.
(3) In small districts there is little or no water running in the sewers at certain periods of the day.

(4) Requires a good system of ventilation.

The author is in favour of the separate system, especially with the bacteriological method of treatment. But the system should take all the first washings of a storm, not only because they are so foul, but also to occasionally flush the sewers at a small cost.

To obtain this water, large tanks would have to be made in each street, or series of streets, to take the surface flow. Immediately the tank became full, the water should flow direct into a surface water sewer communicating with a stream or river. The water in the tank itself should not be discharged until the storm had passed over—an arrangement which could easily be made.

156. Suppose the rain water be falling at the rate of ½ inch per hour, as only 50 per cent. of that water gets into the sewer during that hour, the fall may be taken as ¼ inch per hour. The average house has an area of 3000 square feet; then, for 100 houses, the tank should have, for a 20 minutes flow, a capacity of 2000 cubic feet, and the dimensions be, say, 15 feet by 20 feet by 7 feet. The sewers supplying these tanks might be made with a self-cleansing velocity and be trapped so that sewer gas could not penetrate higher than this point.

It will be seen from Art. 248, on p. 179, that, on the average, rain falls on one out of every four days throughout the year; it will therefore be seen that the sewers could, by these means, be flushed with a regularity which is not usually given to them by artificial means.

The sewers above the tanks would rarely have to be flushed, because they would be made with a self-cleansing velocity. Those below the tanks could not have a better flush than a quantity equal to 12,000 gallons flowing down at a speed as fast as the sewer could take it.

CHAPTER X.

SEWAGE PUMPING.

157. IN Chapter V. it has been shown how the engineer may ascertain the horse-power of an engine required to raise sewage from a low to a higher level.

At sewage disposal works the Local Government Board require that, where the combined system is adopted, the treatment shall provide for six times the daily dry weather flow in some form or other. The volume of liquid to be pumped will therefore be six times the volume of sewage from that area.

An illustration of the manner in which a pumping scheme is devised will perhaps be the simpler method of explanation.

A town has a population of 15,000. The distance from the pumping station to the point of discharge will be the length of the rising main, say 1 mile. The height to be lifted is 100 feet. The flow of sewage is assumed to be 20 gallons per head per day; the total daily flow would therefore be 300,000 gallons. As the flow varies and the greatest rate is 70 per cent. of the total flow in 8 hours, the velocity will, during this part of the day, be at the rate of 630,000 gallons per day, or 0·861 cubic feet per second. The minimum flow would be about 0·108 cubic feet per second. The average flow would be 0·557 cubic feet per second.

Six times this latter velocity will give the maximum velocity that the pumps will be called upon to deal with = 3·342 cubic feet per second.

The normal flow would, in this case, be 0·861 cubic feet per second, and it would be advisable that the rising main should be either in duplicate or triplicate, so that a self-cleansing velocity may be maintained through the pipes. Now assume the size of the rising main to be 9 inches in diameter, and the area = 0·4417 square feet, the speed required to discharge $\frac{3{\cdot}342}{2}$ cubic feet per second would be

$$\frac{3{\cdot}342}{2 \times 0{\cdot}4417} = 3{\cdot}8 \text{ feet per second.}$$

We may find the head which has to be overcome through friction along the sides of the pipes by using Santo Crimp and Bruge's formula—

$$v = 124 \sqrt[3]{r^2} \sqrt{s},$$

$$v = 3{\cdot}8, \quad r = \frac{9}{12 \times 4}, \quad s = \frac{h}{5280},$$

$$\therefore h = \frac{(3{\cdot}8)^2 \times 5280}{(124)^2 \times \sqrt[3]{\left(\frac{9}{12 \times 4}\right)^4}} = 46{\cdot}4.$$

To this must be added the loss of head due to velocity, bends, &c., but to simplify matters these have been left out of the present calculations. We now obtain the total head through which the water has to be pumped—*i.e.*, the actual head plus that due to friction to be 146·4 feet.

$$\text{The water horse-power} = \frac{h \times w \times a \times v}{33{,}000},$$

where h = head of water, w = weight of a cubic foot of water, a = area of pipe, and v = velocity in feet per minute;

$$\therefore \text{ water H.P.} = \frac{62{\cdot}5 \times {\cdot}4417 \times 60 \times 3{\cdot}8 \times 146{\cdot}4}{33{,}000} = 28 \text{ nearly.}$$

The indicated horse-power, after allowing for leakages and efficiency of the engine, would be

$$\text{I.H.P.} = \frac{28 \times 100 \times 100}{85 \times 95} = 34{\cdot}7.$$

There would, therefore, be required two engines, each of 34·7 indicated horse power, to deal with this sewage, through two rising mains each 9 inches in diameter.

One engine and one rising main, if so designed, could do this work; but it would be a waste of power to work a large engine to do the work which another half the size could do on each day the flow remained at its dry weather state, and even up to the time when the flow had increased to three times its average flow.

158. These engines are capable of dealing with 1·671 cubic feet per second, but the minimum flow is ·108 cubic foot per second. If this engine is to deal with the sewage as it enters the sewage well, it would have to be constructed so that its speed could be reduced one-sixteenth, or else for several hours it would have to stop until there was sufficient to keep it running at its normal speed. It is unusual for an engine to be so constructed, and the only course to adopt would be to adopt a smaller size of engine to take the flow during the night, and in the day time to put a larger one on to take the increased volume, the third and large engine being used in times of storm only. Another method would be to construct a tank holding the 16 hours' night flow of the sewage; in the case under notice this would be of 90,000 gallons capacity. Then the engine would work at its full normal speed during the remaining 8 hours; it would then take not only the whole of the sewage that had flowed during the night, but also the quantity that

is flowing during the time the pump is working. By this scheme of working only one set of men need be employed, whereas in the other scheme either two or three shifts would have to be resorted to. In the case where the engine is working only 8 hours of the day there would have to be preparations for a storm, both engines being set to work whenever there should happen to be a rainfall, especially when it promises to develop into one of some magnitude.

159. Engines in duplicate are especially useful as a provision against breakdowns (which happens in sewage pumping engines more frequently than in engines for pumping clean water); as the parts are similar, and the broken or damaged piece is easily replaced. The breakdowns in the case of dissimilar engines are sometimes difficult to rectify, and when there is only one engine they are intensified.

The duplication of the rising main is not so necessary as that of the engines, the rising main rarely bursting or giving way except where the head is great.

The centrifugal pumps are not economical when the height the water has to be raised exceeds 50 feet. When the height exceeds 50 feet, pumps of the combined forcing and lift type should be employed.

There are other forces than steam—*e.g.*, gas, electricity, water, and compressed air.

160. **Water or hydraulic motors**, where water is plentiful, and there is sufficient head, might prove to be very economical and well worthy of consideration; a water motor is shown on p. 46, Fig. 35. These engines require very little attention, and may be classed from this point of view with a gas engine. Neither chimney nor boilers are required. A valve regulates the quantity of water passing into the piston, and this valve can be attached to a float in the sewage well, which, as it rises and falls, will correspondingly open or close the valve supplying the water to the motor. The machine may be simplified to the greatest degree.

161. The **pneumatic system** is used with success in many towns, and is greatly appreciated in low-lying and flat districts. An air-compressing plant is put down in some position convenient and central to the places where it is required to raise the sewage. The compressed air is supplied to an ejector—*i.e.*, a small tank made absolutely air-tight and capable of resisting the head of water, which is represented by the height the sewage is to be lifted in all its parts. The ejector itself works automatically; the working is very simple, and there is little liability to get out of order. Compressed air is undoubtedly much easier to deal with than water under pressure. It is, on the other hand, more difficult to locate a leakage in a tube conveying compressed air, whereas a leakage in a water pipe is much easier to find. (See Art. 98.)

Fig. 103 shows a section of an ejector. The sewage gravitates from the sewers into the inlet pipe A, the valve being open allows the sewage to rise in the chamber, lifting with it the cup C, which gradually immerses the bell D, so enclosing a small amount of air; this becomes compressed, and lifts the bell, spindle, &c., attached to the valve controlling the supply of compressed air, thereby opening it; at once the air rushes in, and the pressure on the sewage closes the inlet valve B (Fig. 104), opens the outlet valve C

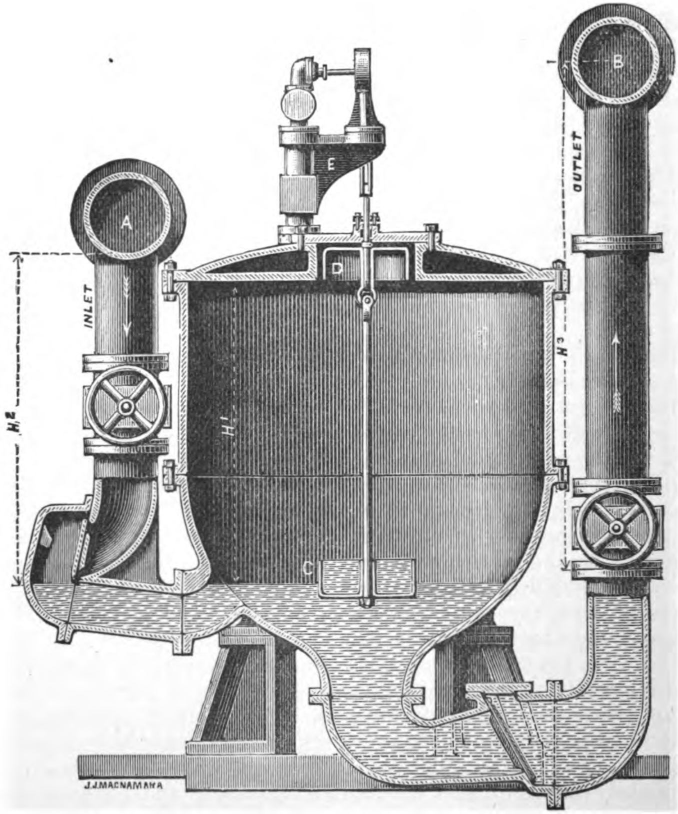


Fig. 103.—Shone's pneumatic ejector.

(Fig. 104), and drives the contents of the chamber into the outlet pipe B (Fig. 103), and thence into some other sewer at a higher level. The sewage, in being driven out of the chamber, brings down with it the cup; when it reaches a certain fixed point it closes the air valve, at the same time allowing the air in the chamber to exhaust down to atmospheric pressure; thus the sewage in the chamber is not completely driven out, but retains a level something like that shown in the sketch. The liquid in the rising main closes the outlet valve C, and the sewage once more enters through the inlet valve B into the chamber.

The working parts are few in number, so that there is little to get out of working order; there are no tooled surfaces with which the sewage may come in contact, and the whole of the ejector is coated with Dr. Angus Smith's solution, which prevents the iron from being corroded. The inlet is wide, and allows all solids that may flow through the sewer to pass into the chamber freely; similarly, the outlet allows free egress.

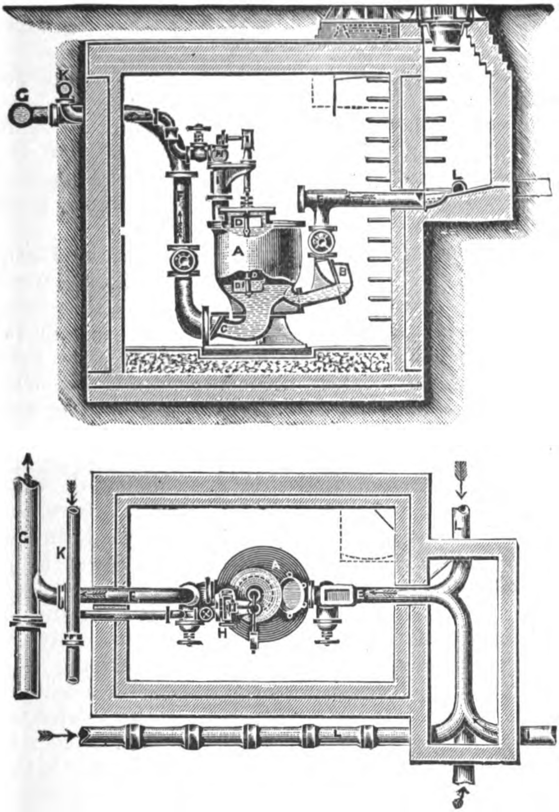


Fig. 104.—Shone's pneumatic ejector in brick chamber.

The advantages claimed for the system over steam pumps are—

(1) There is no screening or straining of sewage.

(2) The solids go to the bottom of the ejector, and, consequently, are the first to get into the outlet and have a body of water to follow them.

Other advantages are—

(1) The system gives a good flush to the sewer into which it discharges.

(2) The chamber is a perfect severance from other sewers.

(3) Sewers may be laid to give a self-cleansing flow, as the ejectors may be placed in any position.

(4) The ejectors may be used for the transmission of pail refuse and sludge.

Fig. 104 shows the ejector as usually erected. A is the ejector, B the sewage inlet valve, C the outlet valve, D the bell, D^1 and O the cup and spindle respectively, L the sewer supplying the sewage to the lifter, K compresses air supply main, F the sewage outlet pipe, G the sewage delivery main.

162. By the use of this system a town may be divided into separate sewerage districts. The sewage should be, if possible, freed from as much rain water as possible, as the sewage could then be carried in small pipes at shallow depths. Once it passes the ejector, it could be sent in sealed pipes to its destination, and arrive there before it has time to decompose. Thus the scheme admits of the separate system of drainage, which is to a certain extent desirable, and it also assists in the ventilation of the sewers by preventing the solid or liquid matter giving off offensive odours through decomposition. With the system there is a quantity of exhaust air which is discharged from the ejector after it passes the sewage into the outlet pipe. This air may be used in causing a current of air to flow through the gravitation sewer (L), but this will be illustrated in Art. 189, Chap. XI.

163. Generally speaking, a system of sewage on the pneumatic system here described will be found to be more costly than a gravitation scheme; but some of the systems that have been carried out in various towns have cost a very reasonable amount per head of population, and compare very favourably with what a gravitation scheme might have cost in the same towns. The cost cannot be even approximated by that estimated for any town, as all cases differ considerably. Each must be taken on its merits. The engineer must also infer for himself whether the system, provided that it did cost more than any other scheme, has or has not its sanitary compensations. The Liernur pneumatic sewerage system is described in Art. 298.

164. A low level sewer very often is only a short distance from a high level sewer, and in many cases the low-level is very small compared with the high level zone, and the sewage is consequently less in volume.

It has, therefore, been reasoned that the sewage from the low level may be forced into the higher zone by using the sewage in the sewer on the higher level from such a point that will give the air pressure necessary to raise the sewage as required.

Adam's patent sewage lift is illustrated in Fig. 105. Two

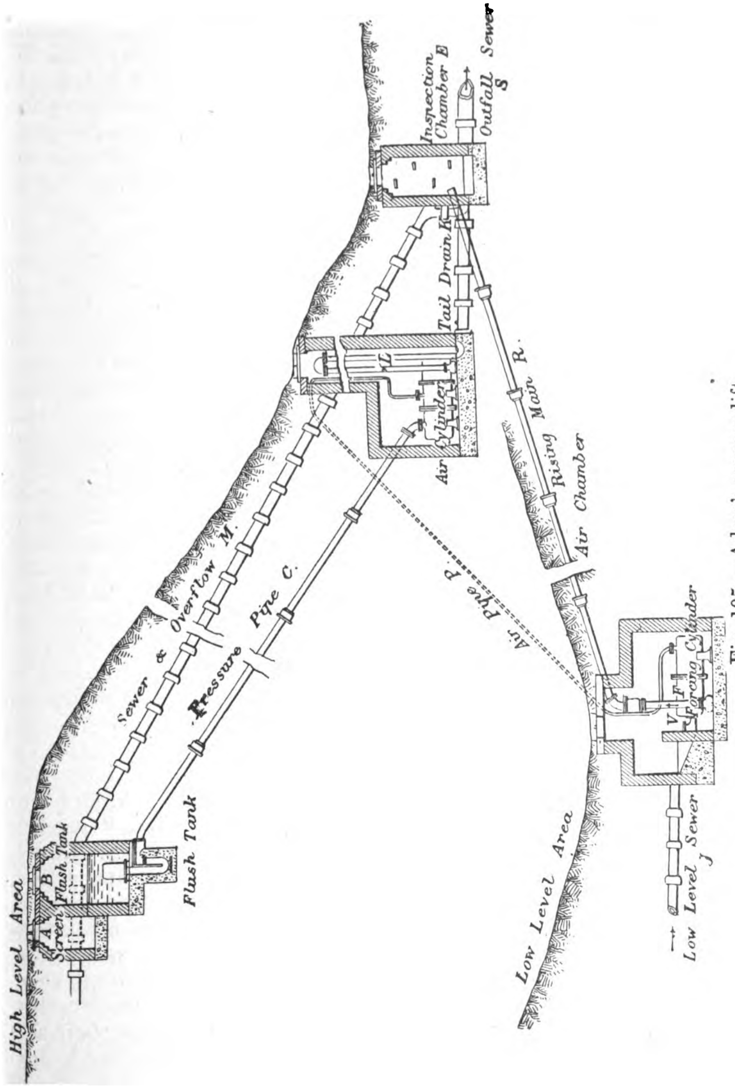


Fig. 105.—Adam's sewage lift.

vessels are employed—the "air" and "forcing" cylinders respectively. These are connected by an air pipe. The forcing cylinder receives the sewage to be raised, and the air cylinder receives the liquid which is to give the required air pressure. In the chamber A is a screen to prevent solids from entering the flush tank B. T is the flushing syphon which discharges through the pressure pipe C into the air cylinder D, forcing the air which was contained in the latter into the air pipe P, which, as will be noticed, is higher than the syphon pipe L for a reason to be explained later on. The sewage from the low level sewer has flowed into the forcing cylinder F through the valve V. Here there is also a float arrangement which, when the cylinder is full, communicates with the flush tank, and the latter at once discharges. The air through the pipe P presses on the sewage, closes the valve V, and displaces the liquid into the rising main R, and from thence into the inspection chamber and outfall sewer. The liquid which has been discharged from the pressure pipe C into the air cylinder is, immediately the latter is filled, syphoned off by the syphon L into the inspection chamber, and thence into the outfall sewer. The cylinder is then ready for the next flush, having received air from the forcing cylinder or flush tank. The air pipe must be higher than the syphon pipe, to prevent the sewage in the air cylinder from going down the air pipe and into the forcing cylinder.

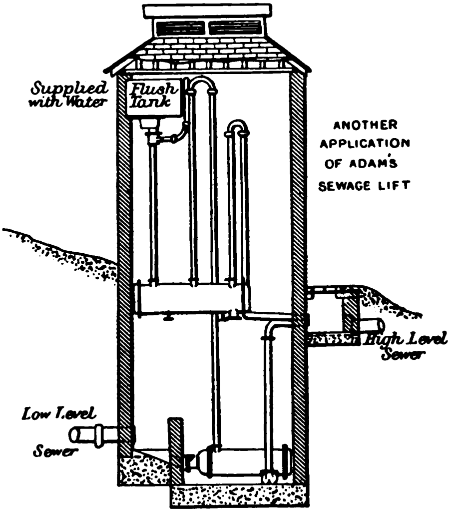


Fig. 106.—Adam's sewage lift.

The rising main commences at the underside of the forcing cylinder, and the air pipe enters at the opposite end and at the top of the cylinder to ensure its proper discharge.

The flush chamber will be of such size as will fill the air cylinder and the two syphon pipes, which are to empty the air cylinders into the inspection chamber.

The height of the air pipe above the cylinder will exceed the height the water has to be pumped.

Fig. 106 gives an illustration showing how the sewage may be lifted by means of fresh water from a low to a higher level. The lifts may thus be used in cellars and underground urinals. The flush tank, air and forcing cylinders are placed vertically over one another to economise space.

165. Many towns have a scheme of sewerage which is capable of dealing with the sewerage up to a certain defined line, so that any of the sewers below that point would be flooded at the first rainfall. In most cases it is an advisable course to cut these sewers off at these points, and construct another sewer to receive the higher parts so cut off, which new sewer would be called an intercepting sewer. This sewer might easily run direct to the purification area, and relieve very greatly the lower area, and if there is a pumping station, lessen the pumping area.

Where self-cleansing sewers are to be laid, means must be adopted to attain this result. In the majority of cases a pumping scheme will be necessary. A few feet in a pump well will mean a considerable difference to the inclinations of the sewers, but it also means a very large cost in the construction of the sewers, to which must be added the expenses of pumping.

CHAPTER XI.

SEWER VENTILATION.

166. In a sewer, through which sewage may or may not be flowing, there is to be found an atmosphere differing in density, temperature, and composition from that found on the surface of the ground above.

Sewage gives off certain gases, depending on the state or condition of the sewage. These gases mingling with the air form a mixture which is unpleasing to the senses.

It is assumed by many authorities that if the sewage flowing in the sewer contain germs of disease, these germs will be given off into the air, and will also thrive in the slime and deposit which is seen on the walls.

It is evident, then, that the health of persons would be somewhat endangered should they happen to breathe the air which may issue through any accidental openings communicating directly with the sewers, or through the medium of manhole covers or ventilating gratings. There is, of course, less risk if the air, before it reaches the breathing atmosphere, traverses some distance in the open; but this is a question that can hardly be entered into, as it is so difficult to determine the oxidising effect of the air after passing over any certain fixed distance.

The prevention of these gases reaching the surface in a noxious and offensive state has been the subject of much thought and study on the part of both medical men and sanitary engineers. It is a question that admits of many views, some of which are directly antagonistic, while others are independent and peculiar.

In this chapter we purpose giving a brief notice of the principal characteristics of the atmosphere bearing upon sewer gas and the methods adopted for its purification.

167. When air is heated it expands, and when cooled it contracts. It follows, then, that cold air is denser than warm air, and that the latter will ascend through the former. Such an ascent will decrease the atmospheric pressure. Gases diffuse at a rate in inverse ratio to their densities; thus two gases of unequal densities, if placed in contact, soon produce an uniform mixture, the heavy particles passing in one direction and the light ones in the opposite direction until there is perfect mingling.

The sea gives off a water vapour which is lighter than air, a mixture is formed, the density of the atmosphere is lowered, and therefore the local pressure is less.

A relatively warm current ascends in the atmosphere into a cold zone, where the aqueous vapour in it is condensed into cloud as soon as the temperature is reduced below the dew point. A warm current of air flowing up a mountain is cooled, and the vapour in it similarly condensed. Clouds may often be observed about a mountain when the atmosphere in the same plane at a distance from it is cloudless.

Every pound of vapour during its condensation liberates enough heat to melt about five pounds of cast iron; from this we can understand why it is that a rise of temperature often follows a heavy rainfall.

Water exposed to air gives off vapour until the tension of the vapour in the air equals the tension of the vapour at the surface of the water; at this point the air is said to be "saturated." The quantity of vapour required to saturate the air varies with the temperature; if, when saturated, the temperature of the air is increased, the air will be capable of taking up more moisture, but if the temperature of the air is lowered, a definite surplus quantity of moisture is separated in a liquid or solid form, and appears as mist, rain, snow, or hail.

Atmospheric air contains about one-fifth its volume of oxygen, the remaining four-fifths being nitrogen; the density of nitrogen is 0·9713; oxygen, 1·1056; carbonic acid, 1·5203; air, 1·000; water vapour, 0·622.

Atmospheric air is 820 times lighter than water. 100 cubic inches of air = 31 grains, and 13 cubic feet of air = 1 lb.

We may mention here that light favours oxidation, and that Dr. Frankland has pointed out the important share light has in aiding the vital processes of plants and of animals, as also its efficiency as a purifying and curative agent. The treatment of smallpox patients in a room from which the ultra-violet rays are excluded by red panes appears to have been very successful.

168. The air in a sewer is saturated, the sides and walls being usually covered with moisture; it is felt to be damp almost as soon as we descend into it. The air of a sewer is always varying in temperature, as both hot and cold water are allowed to enter at all times of the day

Sewer gas is a mixture of many gases, the composition depending on the state of the sewage flowing through. The following are the more prominent:—Carbonic acid (CO_2), nitrogen (N_2), carburetted hydrogen (CH_4), sulphuretted hydrogen (SH_2), carbon disulphide (CS_2), a mixture of carbonic acid and carbonic oxide (CO_2CO), ammonium sulphide (AmS_2 or NH_4S_2), moisture (H_2O), and compounds of ammonia allied to methylamine and ethylamine with offensive odours. Certain of these gases are innocuous, while others, in an undiluted state, are poisonous.

M. Duchâtelet, in examining the air in a sewer in Paris, found it to contain 3 per cent. of sulphuretted hydrogen (SH_2) and 13·8 per cent. of oxygen, whereas pure air contains 20·7 per cent. of oxygen.

The conclusions of many medical men, eminent in their profession, with regard to the question whether diseases may be conveyed by the gases which emanate from sewers are difficult to reconcile, as there is no definiteness about them.

The late Sir W. B. Richardson said—"Sewer air may become the bearer of those poisons of the spreading or communicable diseases which are volatile and easily diffusible. Some think typhoid fever and cholera may be communicated in this manner, but . . . I have not been able to satisfy myself that the poison was actually conveyed by the air and absorbed in the process of respiration. Most frequently sewer emanation, charged with the specific poison of the said communicable diseases, is carried into the water cistern, into milk, or into some article that is partaken of as food or drink." Dr. Hime, M.O.H., Bradford, 1891, has said "he believed there is no authentic record of the disease germ of any kind having ever been found in sewer air."

On the other hand, Dr. Corfield and Dr. Parkes, in their work on "Hygiene and Public Health" (1892), claim that little doubt can be entertained that sewer gas in contact with infected materials becomes imbued with contagious properties, and that enteric fever has resulted through inhalation of sewer air, no other means being ascertainable by which the infected person could have been brought in contact with contagion. They also claim that there are records of specific contamination of drinking water in cisterns and mains by such air.

Professor A. Roche in 1894 directed attention to the spread of typhoid fever by the discharge into sewers of the dejects in an insufficiently disinfected condition, it being generally admitted that the chief contagion of typhoid resides in the alvine discharges, which, if not rendered sterile by disinfectants, specifically infect the sewage, and wherever it goes it carries the fever with it.

Much more might be written giving the evidence or statements of medical men affirming their inability to accept the conclusion that sewer air does act as a conveyor of disease germs; and, again, other instances may be given where they are fully assured that typhoid fever and other diseases may be spread by the inhalation of the germs of the diseases carried by sewer gases.

The balance of opinion is on the side of the germs being carried by the gases, and only then under circumstances about to be explained.

169. It is admitted that germs will not be dispersed into the air if the sewage be fresh or if it has not begun to ferment. The point where the sewage begins to ferment will never be constant in any sewer—*e.g.*, hot liquid, such as condensing water, &c., would speedily be the means of decomposing sewage matter, so that the air may

become dangerous after traversing only a short distance. Liquid flowing easily, without hindrance and in large bulk, is less likely to give off dangerous particles into the air than if the sewage has a sudden fall in the sewer owing to a block, or if side junctions allow water from branch drains to fall on to the flowing sewage. It has been proved that, after being stirred vigorously into a froth, infected sewage will not give off dangerous germs, but the bursting of bubbles has a marked effect on the surrounding air.

It will be a matter of frequent observance that rivers (locked rivers especially) below any sewage outfall are very black in colour, and there is continually large and gaseous masses rising to the surface. On arriving there they burst with bubbles and tinge the whole mass of water with a black coloration. There can be little doubt that, if the water contained matter or germs of an infectious nature, at these places the air must also become laden with the micro-organisms. In any case, the atmosphere above such a place has invariably a most offensive smell, which demonstrates that gases have been given off, and as micro-organisms are infinitesimally small and light in weight, the probability is, they will also become embodied with the atmosphere and conveyed by the wind to some new place in which they may thrive, become dormant or non-effective through want of the food that is necessary for their existence.

Professor Pumpelly, of the United States Geological Survey, in Supplement 13, "National Board of Health Bulletin," says—"At normal summer temperatures no germs were given off from the decomposing liquids wherever their surfaces remained unbroken, even though, in some of the experiments, the air was continuously conducted over them in a slow current. When the surfaces of the liquid were broken by the bursting of bubbles, germs were invariably given off, and the sterilised infusions were infected."

As to whether germs may not be given off from putrefying liquids, Miquel, in 1878 (*Annuaire Météorologique de Montsouris*, p. 540), says that "in the evaporation of putrid liquids at temperatures of 104° C. to 112° C. germs are given off;" this is, however, doubted, and the results are stated to be due to the drying of the film at the edge of the liquid, and the subsequent detachment of this film by the air current. Such temperatures as these are never observed in sewer air.

170. It must be cognisant to all persons who have been connected with sewers for any length of time that those men who practically live in the sewers, who are in and about sewage matter from one year's end to another, rarely, if ever, ail anything that may be traced to the effects of the air from sewers. The author has, in his own experience, known men who have attained a ripe old age and who have, almost continuously from boyhood, been in and out of sewers, cleaning out all kinds of filth and stinking obstructions,

and are doing so to-day, without feeling any ill effects. The health of those who clean out the wet middens, the pail closets, and those rotten cesspits which abound in almost every town is invariably good. The author has himself lived, during the daytime, continuously on a sewage farm for nearly twelve months, and a large proportion of his time was spent within a few yards of the sewage outfall and tanks holding about one million gallons of sewage. During that time he never knew what it was to be in anything but the best of health. The watermen on two farms with whom he has been acquainted, and who distributed the sewage over the land, never complained of ill-health or sickness that could be possibly attributed to breathing sewage air. Nuisance inspectors who have to supervise the disinfection of a house where there has been an infectious disease, and who have to seek out all nuisances and have them abated, and doctors who attend patients stricken down with infectious diseases, rarely take the germs into their system. The dissecting-room of a hospital where bodies are in different stages of decomposition make many persons faint and sick on entering, but those who are examining the bodies are immune.

It is known that persons having visited a health resort and returned home have, after the usual period, developed typhoid fever, diphtheria, or some other disease conveyable by the air, water, or milk which was obtained at the resort, yet the townspeople with whom they have lived have to all appearances perfect health, and have breathed the same air and drunk the same water or milk, as the case may be.

These are cases which are easily obtainable. The Koch system of inoculation may explain these peculiar facts, that persons involuntarily and almost constantly take into their systems infinitesimal doses, each dose being such as might cause some inconvenience, but no virulent disease, and that the inoculated material has so pervaded their systems as to render them proof against subsequent exposure to any stronger dose. Nevertheless, Dr. George Johnson has described cases of albuminuria and kidney disease, which he considers were the result of long-continued sewer gas inhalation.

171. Professor Tyndal has said that "epidemic disease may be defined as a conflict between the person smitten with it and the specific organism which multiplies at his expense, appropriating his air and moisture, disintegrating his tissues, and poisoning him by the decompositions incident to its growth."

The germs will thrive and propagate only in those bodies which are favourable for their reception. Epidemic disease will not affect a person who keeps himself in good health—*i.e.*, free from colds, &c., lives a healthy life by spending as much time as possible out of doors, and is scrupulously clean about his body and in the house in which he may live.

Should germs of disease be added to a quantity of pure water, they will become dormant, or die from want of the filth they live upon, but where the water is polluted with organic matter then they will develop to a considerable degree. It has been observed that under very favourable circumstances the most prolific of these germs double in every twenty minutes, which means that in about five hours one germ would have 32,000 offspring; this, of course, would not be an actual case, as the conditions would require to be exceptionally good for their development, but it shows to what extent germs may increase.

172. The following conclusions may readily be drawn from the above remarks:—

(1) The sewage must have just sufficient velocity that both solids and liquid will flow together; sewage may have too great a velocity when these conditions cannot be attained, especially in sewers which have only a small and intermittent flow (Art. 111).

(2) The junctions of branch drains should be such that liquid may join with liquid without causing bubbles, and without dropping on to the sewage flowing in the main sewer.

(3) Sewers should be formed into districts, each district being entirely cut off from any other, and the outfall sewer should be entered only by the fewest connections, and the connections should have intercepting traps at their junction with the main sewer.

(4) Sewers should be disconnected from the air at the point where the sewage shows signs of putrefaction, or where the air may be termed permanently foul.

173. In the majority of schemes it is usual to divide the sewerage system into districts or areas, which are called ventilating zones, thus confining the noxious gases from any district to its own generating area. This method is a very advisable course, and should be adopted in all cases. It is accomplished by placing an intercepting trap in the sewer at a manhole, and at a selected point such as the junction of the main tributary sewer.

This is done to house drains, and is perhaps a surer plan of preventing the foul air from reaching the houses than if it were left without a trap. Fig. 39 shows the section of an intercepting chamber and manhole; the grating at the top is sometimes left open to the air; this is supposed to act as an air inlet, and the soil-pipe shaft as the air outlet. But, as a matter of fact, these gratings act as air outlets or upcast shafts, and if there is any possibility of the drain holding foul gases detrimental to the health, a rush of water would sweep it forward to the yard surface through this grating. The persons living in the house and using the yard are then in danger of inhaling the gases. If any so-called surface grates are put in with the intention that they should act as air inlets, they should be so made that they will close when the air forces its way from the sewer outwards. This has been attempted by blocking the grating on the intercepting trap, and carrying a pipe 3 feet up an adjoining wall; the pipe is fitted with an open head, in which is placed a mica flap; the flap is supposed to prevent the air from issuing from the chamber. In many cases it also prevents air from entering the chamber. In the author's opinion it is not advisable to place intercepting traps in the yards of houses.

174. A sanitary engineer has to remedy any nuisance that may arise in connection with a sewer; there are genuine cases and imaginary cases;* the latter are aimed at the open manhole cover, and not at the sewer gases.

The engineer, on examining a complaint, will find whether the nuisance is continual or occasional. If occasional, an examination should be made of the sewer above or below the point where the objectionable smell is in evidence. An obstruction will generally be found in the flow which has been giving off the noxious gas, and when removed either by sending a man up to it, by a flush of a large body of water, or by a combination of these, the nuisance will be removed. These are usually sure remedies for most complaints.

But if the nuisance cannot be abated by these means, and the smell is from one particular manhole, or from two or three, then the sewer may be at fault; sometimes additional surface ventilating manholes may be requisite.

In every case there is a cause, and that cause should be defined.

175. Manholes open to the atmosphere should only be placed in those positions where air may be drawn into the sewer by means of the velocity of the sewage in the sewers, and from the point where the manholes continue to give off offensive fumes they should be blocked up. A further examination at a later period will demonstrate whether these fumes issue from those that have been left open. If the air from those which have been left open remains unobjectionable, then the foul atmosphere is locked, and cannot but remain there until the manhole covers are lifted.

At the dividing points the sewer may be intercepted by a trap, flap valve, or as shown by Fig. 113. It must be apparent that either the atmospheric air has been brought into the sewer and has assisted in relatively purifying the gases up to this point, or the sewage has begun to decompose to such a degree as to exhaust the oxidising effect of the air in the sewer, and require more oxygen from some other source to neutralise the noxious character.

Objectionable gases are frequently to be found issuing from the

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* The author on one occasion had continual complaints from a gentleman respecting the offensive smell from a certain manhole on a sewer; on no occasion could we detect the slightest trace of a smell of any description. Orders were given that the manhole should be blocked, so that no sewer air could get through to the atmosphere in any way, but the cover was left exactly as before. A few days passed, and another complaint was laid, which we demonstrated to be a fabrication.

open manholes at the head of a sewer. This is accounted for by the fact that there is very little sewage flowing, and the air instead of being drawn into the sewer is exhausted from it. Where there is to be found a sewer in which the sewage flows only intermittently, it should be trapped from that portion which has a continual flow. The manholes above this point should not be open to the atmosphere.

Soil pipes only should be ventilated, as these may occasionally be relied upon to supply air to the sewers by the body of water which is so suddenly emptied into them from the water-closets.

176. Care must be exercised in providing such openings to the atmosphere as will prevent the gases which the sewage generates from forcing an entrance through any traps into dwelling-houses, or into places where it was undesirable that the fumes should have access.

If, however, the gases were oxidised and rendered innocuous, then these openings would not apparently be so necessary, but the stage has not yet been arrived at when the air from sewers may have as free access as the atmospheric air.

If there be no soil pipes in a certain drainage area, then separate ventilating pipes may be erected to serve the purpose of relieving the tension of the sewer atmosphere.

177. There are several courses which may be adopted to remedy a noxious and dangerous atmosphere which may be located in a sewer:—

(1) Providing means whereby the gases are sent into higher zones of the atmosphere (above 30 feet from the surface).

(2) Locking the air in the sewers, and providing shafts above the intercepting traps.

(3) Purifying the gases before they reach the atmosphere—viz., at the manhole cover.

(4) Purifying or deodorising the sewage, before it reaches the decomposing stage, in the sewer itself.

(5) Purifying the air in the sewer.

178. The author is convinced that the erection of ventilating pipes in the ordinary way does not serve the purpose in the slightest degree; the shaft will not, in most cases, ventilate itself; often enough the air is merely oscillating in the pipe. The movement of the air in the pipe depends on the direction of the wind and its intensity, the atmospheric temperature, and the temperature of the air in the sewer and shaft.

By retaining the air in the sewer itself, it cannot do the slightest harm to any person. The only danger that might arise is when the men employed in examining the sewers enter this portion without first seeing that the air is purified.

179. The author, in 1888, had to inspect certain sewage tanks which were built 19 years previously; they had never been opened or cleaned in any way during that period. They were covered

with concrete arches, and the manhole covers were boarded over, so that the interior was practically dark. On descending into the tank, instead of finding them to be full of sludge, as was expected, he was agreeably surprised on breaking through the surface to find that it only consisted of a thick strong cake of sludge about 4 or 5 inches in thickness floating on the top of the water; the bottom of the tank was as clean as when it was laid, except for about a few inches of fine gravel. It was not explained until more recent years developed the theory that micro-organisms had been at work and consumed all the filth.

More recently he had to deal with an old-fashioned system of sewerage; there were a large number of manholes, a few of which were exposed to the atmosphere, but the majority were left covered over about 2 to 3 feet below the surface. On examining the sewers, in no case was the sewer air apparently foul or disagreeable.

In the light of recent disclosures, he is inclined to draw the same or similar conclusion with respect to sewer air as he did with the disappearance of the sludge in the tank during the 19 years it had been in operation—*i.e.*, that micro-organisms also act on the foul atmosphere and consume each other, together with the foul matter in the gases which must pervade it. It may possibly be that, in this instance, the sewage flowing down the sewer caused an influx of air through those manholes that were open to the atmosphere and thereby oxidised the gases and kept them free from those particles which might prove dangerous, as the inclination of the sewers rather favours this hypothesis.

It has occasionally occurred that men have lost their lives by inadvertently entering a manhole shaft and an atmosphere in which carbonic acid gas formed a large proportion, but this and other gases are not dangerous in the same sense that we have been considering. The gases are certainly dangerous, but they may be rendered innocuous with comparative ease; it is the germs of disease in the gases that are the troublesome quantity.

The purification of sewage in the future will be either by electrolysis or by a bacterial agency; both seek the same end, but the working of the one is entirely opposite to that of the other; the one aims at the complete destruction of the micro-organisms, and the other encourages their growth.

Those in favour of electrolysis claim one great advantage—that the spread of disease is an impossibility, owing to the removal of the primary cause. If it can be done—and it is possible—the sewage or the sewer air may, in the future, be treated by this process or some other on similar lines which would render the air innocuous and inodorous.

180. The more offensive constituents of sewage are the compounds of ammonia, and it is the aim of sanitary specialists to convert these ammonia compounds into nitrates. Nature does this

somewhat in the following manner:—The organic matter is decomposed by the action of micro-organisms, and is dissolved by the rain which carries it below the surface of the soil; here, in the presence of air, it is converted by bacteria into nitrites, and, by the same agency, the nitrites are converted into nitrates, which is the final state of oxidation; in this state it is assimilated by vegetation. The conversion of the nitrites into nitrates is done in the dark. The soil will not retain the whole of the nitric acid, which is therefore washed away by the next rainfall. If chemists could supply these micro-organisms, it might be possible not only to purify the air, but also the sewage on its way to the sewage works.

181. Many years ago an invention provided for the making of oxygen in the form of ozone. Ozone is oxygen pure and simple, but in a slightly different state; a molecule of oxygen. as a chemist understands it, is made up of two atoms, written O_2, whereas a molecule of ozone is made up of three atoms and is written O_3. Ozone is, popularly speaking, anxious to part with the odd atom in order to become oxygen; it is evidently a good purifier and oxidiser. If this ozone is disseminated into the air of the sewer, other gases will be formed, and the air would expand by reason of the addition. Means would have to be provided in order that the gases could be removed, otherwise they might force a passage through traps into domestic premises.

Mr. Baldwin Latham, M.I.C.E., invented a manhole ventilating shaft in which was placed a spiral basket of charcoal, through which the gases from the sewer had to pass before reaching the atmosphere. A manhole cover invented by Mr. Caink, C.E., seems to have proved effectual in purifying the gases emerging from a sewer. These forms of purifying the gases of sewers are commented upon in Arts. 184 and 185.

The method of purifying or deodorising the sewage as it enters the sewer is dealt with in Art. 190, and Reeves' system of rendering the air in the sewer inodorous by disinfection or deodorisation is also noticed in Art. 190.

There have been many suggestions which were designed to purify the gases in the sewers—*e.g.*, in one case the sewers entering the main sewer were to be trapped; all openings on the main sewer, except that at the head, closed, and the air drawn through the sewer by fans worked by the flow of the sewage; the air, when it reached the outlet, was to be cremated.

Another suggestion has been made—to place disinfectants and deodorisers in the flow of the sewage; but the latter is always fluctuating, and the quantity of disinfectants would be difficult to gauge.

Experiments have been made with certain materials which were to absorb the noxious gases.

Various agents, such as chlorine, &c., have been employed to destroy or annul the dangerous effects of the gases. Electricity and galvanic batteries have been used with the same purpose in view. None of these experiments, however effectual they may have been, have received much encouragement, for it is only by searching diligently that the inventions have been found or the idea made public.

182. The present systems of ventilation may be divided into a series of classes:—(1) Surface ventilation, (2) surface ventilation combined with vertical shafts, (3) ventilating shafts, (4) exhaust cowls, (5) chimney-stack ventilation, (6) disinfectants and deodorisation of the sewage atmosphere, (7) Shone and Ault's ventilating system, (8) Stone's system of purifying the gases.

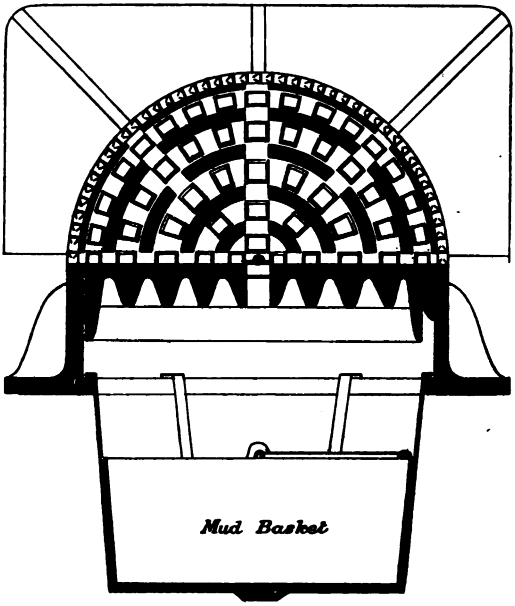


Fig. 107.—Surface ventilators.

183. **Surface Ventilation** is largely adopted all over the country; it consists merely of manholes with covers in the road surface; the covers are perforated as shown in Fig. 107—the circular bands (black) in the plan of the cover indicate the perforations, the mud-basket shown in the section is to catch the road-scrapings, manure, &c., which may drop through the perforations; this basket may be lifted out and emptied occasionally.

The manholes are usually placed from 80 to 100 yards apart at every change of inclination or direction. If a nuisance is created and cannot be removed by cleaning out by hand or flushing, the general practice is (*a*) to close them and take no further action, (*b*) to close the openings and take a pipe from the underside of the cover and connect it to a ventilating pipe erected in the gable of the nearest house or wall, (*c*) to leave the openings in the grating, connect the pipe at the bottom of the manhole and convey it to the ventilating shaft similar to (*b*); the manhole cover is then supposed to act as the air inlet and the shaft as the air outlet.

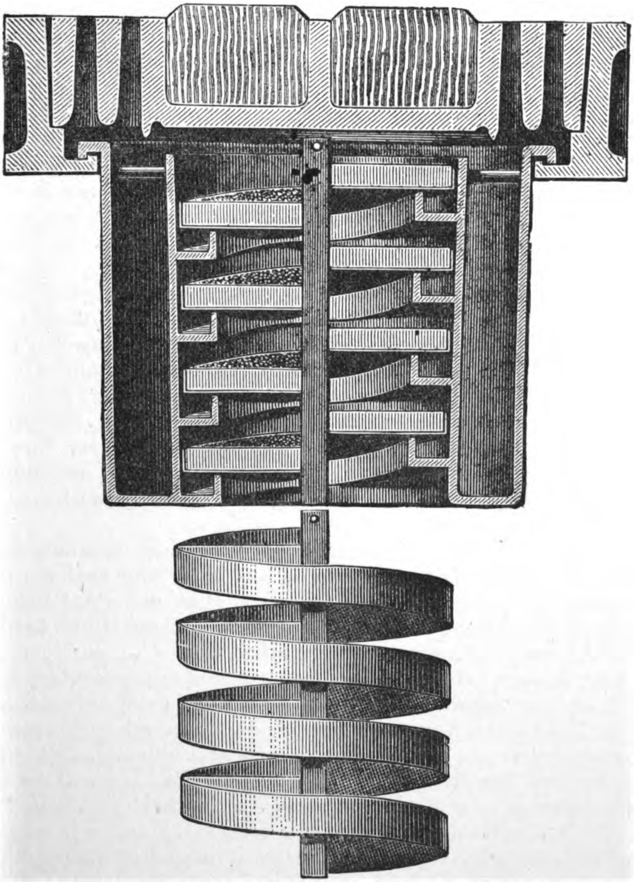


Fig. 108.—Latham's sewer ventilator.

184. There have been many inventions to purify the air as it issued through the manhole cover. Fig. 108 shows the ventilator

designed by Mr. Baldwin Latham, M.I.C.E.; it consists of a spiral tray fixed immediately below the cover as shown; the underside of the tray is perforated so that the air may pass through, the tray is then covered with charcoal, which is an excellent disinfectant, oxidiser, or filtering medium when it is dry. Its failure is due very much to the charcoal becoming damp either through aqueous vapour in the sewer air or in the atmosphere. Charcoal in a dry state is of great value, as the nitrates and ammoniacal compounds can be recovered; it also decomposes certain gases and vapours—*e.g.*, sulphuretted hydrogen, ammonia, &c.—and, by a process of oxidation makes the most noxious air innocent. A remedial measure might be taken to render the charcoal permanently effective; it would take the form of a gas jet under the spiral tray, which would then keep the charcoal free from moisture and also render it more effective in its action; the heat would not have to be so great as to burn the charcoal, but just sufficient to keep the atmosphere, or the charcoal, or both, free from vapour.

185. Another form of manhole cover has been designed by Mr. Caink, of Worcester. The frame of the cover has fluted sides, and is supposed to collect the moisture in the sewer atmosphere; the air eventually has to pass through some cotton wool which is saturated with a disinfectant not affected by dampness.

It is suggested that the germs of disease remain in the air and on the walls of the sewer and manhole; these are, however, washed away by every storm; in the meantime they are rendered harmless to the outside atmosphere by having to pass through an oxidiser.

The inventor says that "sewers are the readiest channels for the dissemination of spores and bacilli, and that the real source of danger to be apprehended from sewer emanations is not sewer air nor even sewer gas *per se*, but the micro-organisms which form the specific of certain diseases. The object is not to purify the air within the sewers, which is inhabited by rats and microbes, but to purify it in its transmission from the sewer to the external atmosphere." The covers have, so it is stated, been used with success in cases where there has been long-standing and objectionable smells.

186. **Surface Ventilation with Vertical Shafts.**—It will be found that manholes have sometimes a shaft similar to that marked *g* in Fig. 110; it may be conveyed up the nearest gable, or it may be a vertical pipe in a footway reaching to a height of about 30 feet. The manhole will probably have a closed cover, but the next above it will be open in order to act as an air inlet. It is questionable whether they serve their purpose or, indeed, act at all in the manner required. The temperature of a sewer or of the gases in a sewer is no doubt fairly constant at all periods of the year, but the temperature of the atmosphere at the street surface is not constant, nor will it agree with the temperature of the air 30 feet above the

ground, which is also variable. It must, therefore, be evident that even those shafts which may be surmounted by an exhaust cowl, such as that shown in Fig. 109, will occasionally act only in a manner contrary to that in which they were designed, or, as has already been observed, the air may merely oscillate in the shaft. It may easily be conceived, indeed, that in certain states of the weather the shaft may become an air inlet, and the surface manhole cover may act as the sewer air outlet.

The velocity acquired by the sewage, together with its volume, must cause in many cases an influx of air from both vertical shafts

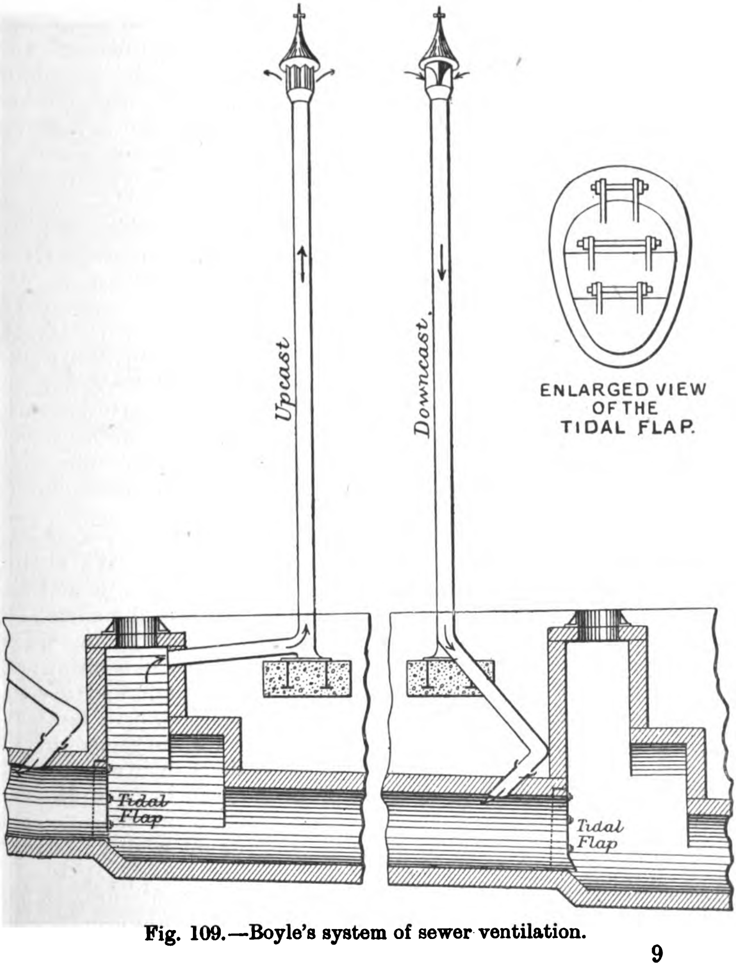


Fig. 109.—Boyle's system of sewer ventilation.

and surface ventilators, even if the vertical shaft should have an exhaust cowl—and, when the velocity is lowered, then sewage air must issue through both shaft and surface ventilators where the sewer is flat in gradient.

187. Fig. 109 shows Boyle's system of sewer ventilation. The downcast and upcast shafts are both placed about 30 feet above the surface of the road. The cowls on the shafts are so constructed as to cause a partial vacuum in the upcast pipe and thus exhaust the air. In the case of the downcast cowl, the plates on which the wind plays are so directed that the effect is to assist the air down the shaft. The tidal flaps limit the area on which the shafts work. In this case it matters little whether the shafts act both as upcasts or both as downcasts, or as upcast and downcast or downcast and upcast respectively. If the shafts do circulate the air—and only experiments with anemometers registering it daily will prove the fact—then the scheme is valuable; there is a doubt, and it requires solving not by laboratory experiments, but by experiments in a system of sewerage. The manhole covers would, of course, be closed.

188. **Chimney Shaft and Gas Lamp Ventilators.**—Attempts have been made to utilise heat for exhausting, burning, and destroying the objectionable elements of sewer gas. In the case of a connection with the chimney shaft of a manufactory, it is admitted that it does draw the air from the sewer, but only from a very limited area, probably only as far as the nearest manhole; so limited, in fact, is its effect that it is hardly worth the expense of the connection. Manufacturers complain that it interferes with the draught, demands a larger chimney, and causes a greater coal consumption in their furnaces; they refuse to allow the connection in many instances. It is important, also, that the furnaces should be in operation day and night and on Sundays.

Included in this section are the sewer air exhausters and destructors by means of coal gas furnaces. In this case the shafts are sometimes ineffective, as the current of air is downwards instead of upwards, and the heat is used in drying the air entering the sewer instead of exhausting and destroying the gases issuing from it. The burners of the Keeling-Holman sewer gas exhauster are placed at the foot of a specially-designed lamp column, and are so placed (in the shape of a cone) that the air must come in contact with the flames before it is allowed to pass into the atmosphere. Another exhauster is formed by a copper tube 4 inches diameter connected direct with the sewer from the lantern in an ordinary lamp-column admitting of this size of tube inside the shaft. The burners in the lantern heat the gases, but cannot wholly destroy them.

These forms of ventilators are said to remove the nuisance. The closing of the manhole cover would also remove the nuisance, but neither would remove the cause of the evil.

Fig. 110.—Shone and Ault's system of sewer ventilation.

189. **Shone and Ault's System** of sewer ventilation is illustrated in Fig. 110; *e* is the ejector exhaust from an ejector, which is just visible, and which was described in Art. 161. It runs, as will be seen, to a nozzle *n* in the chamber *b*. To this chamber is led a pipe *f* from the manhole *m* on the gravitating sewer *d*. *g* is a shaft 30 feet high, to clear all windows. At the head of the sewer is placed an inlet shaft about 10 feet high, with a regulating cap. While the ejector is being filled with sewage the air is displaced, and flows through *e* to the nozzle *n*. This nozzle acts like an injector. The passing of the air causes a vacuum in the nozzle, and therefore air is drawn from the manhole, which is supplied by the inlet shaft at *o*. When the ejector is filled with sewage and the compressed air is allowed to enter, the exhaust valve closes automatically, and the sewage is then forced out. The valve then opens, and the whole volume of compressed air rushes through the exhaust, carrying with it the air from the sewer or sewers which may communicate with the chamber *b*. If the sewers are short the fresh air inlet has to be closed to the smallest extent, and if long, it is opened proportionately. By these means the bulk of air drawn to the nozzles is proportioned to the sewers.

The system is somewhat complex, as it necessitates there being no opening into the sewer, except the one that is regulated. The traps to rain water pipes, w.c.'s, &c., are likely to become untrapped if the pressure drawing the air should be great and the inlet less open than it should be. In times of drought—and, therefore, in times when there is greater danger—the traps are likely to be dry, or have less water than there should be. These may, however, be nullified in some degree by the frequency of the actions of the ejector, which, perhaps, would not allow the time required for foul air to be generated; while by the use of more inlets the possibility of the unsealing of traps would become less probable. The system can be adopted where there are gravitation sewers only by supplying the compressed air direct to the nozzle through a tube *e* connected to an air compressor.

190. **Reeves' System of Purifying the Air in the Sewers.**—Two vessels made of chemical ware are placed in a manhole, as shown in Fig. 111. One of these is filled with strong sulphuric acid, and the other with a specially prepared mixture containing mostly manganate of soda. A water supply is fitted to the latter vessel, and water is allowed to percolate slowly through the manganate, the solution thus obtained falls on to an earthenware splash plate placed below the apparatus. The sulphuric acid is then run at a certain rate on to the same plate, and oxidizes the manganate solution to the permanganate form; in the change heat is generated and vapours of permanganic acid (one of the most powerful deodorants) are evolved, from which the oxygen is readily drawn off by the organic matter in the air of the manhole and sewer.

The permanganate solution falls on to three porcelain pots, on which a spray jet from the water supply is directed, and from the impact the spray becomes attenuated almost to the form of a mist which contains the chemicals in solution, and which, in falling into the sewer, purifies the gases passing up the manhole. The spray eventually reaches the sewage in the sewer and acts as an oxidiser, thereby lessening the probability of the sewage causing a nuisance in the lower areas.

The cost of the apparatus is about £10; then the manhole has to be altered to receive the apparatus, and the annual cost per apparatus is about 43s.

In the construction, care has to be exercised that the water supply is not affected; a drop stop-valve and a syphon are provided, so that the sewage air is not sucked into the main when the pressure in the latter decreases.

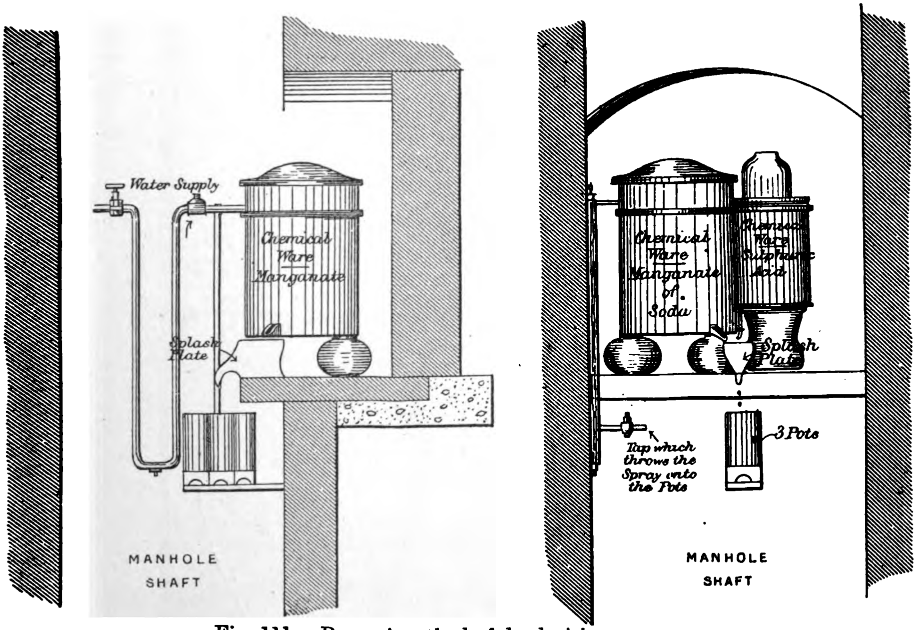


Fig. 111.—Reeves' method of deodorising sewer gas.

191. Now that electricity is so much to the front in many streets of our towns, another, and perhaps a simpler, method might be adopted.

Fans are made so that, merely by applying the current to the same, they will whirl round at an enormous velocity, driving the air through and into any desired place. They are used extensively in offices and hotels for clearing and cooling the atmosphere. The manhole in which the fan would be placed would act as a downcast shaft; an upcast ventilating shaft would be placed in the sphere of action of the fan.

192. Messrs. Stone & Co. have invented an apparatus which can be placed in any convenient position in the upper part of the sewer to be ventilated. The apparatus is illustrated in Fig. 112. A small jet of water from the town supply is turned on by the cock A; this forcing its way through the nozzle B creates a partial

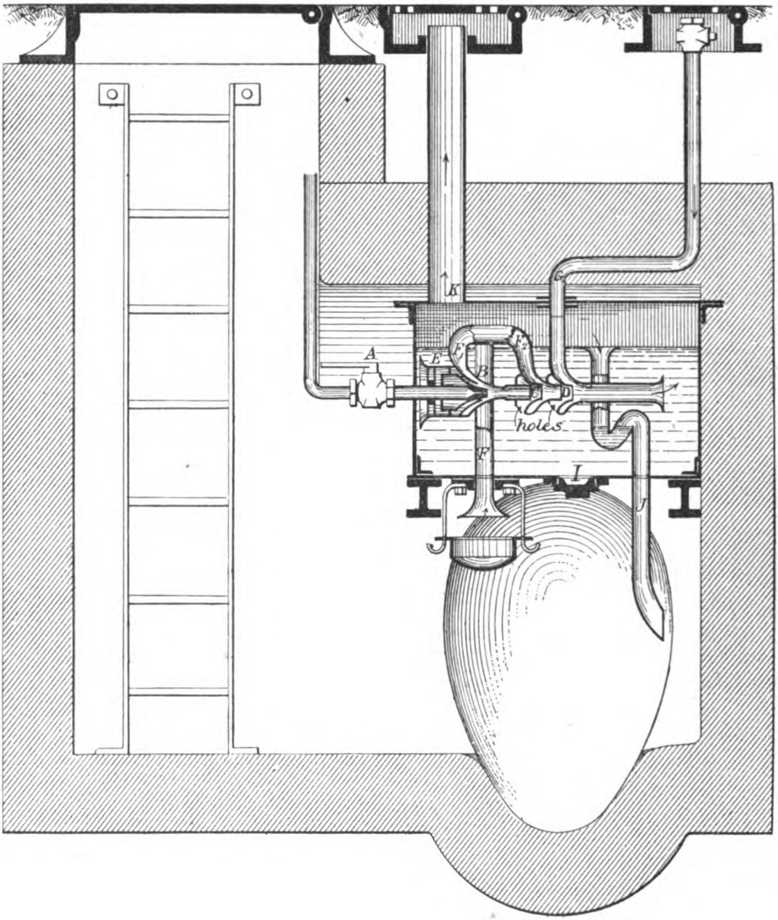


Fig. 112.—Stone's apparatus.

vacuum at the points B, C, and D. The tank being full of water, a quantity is thus drawn into the tube through the bell E, and also through the holes at C and D. Sewer gas is also drawn into the apparatus from the sewer through the bell F, and upwards to the points B and C through F^1 and F^2. Fresh air is drawn from the surface of the road and meets the water and gas at the point D. The sewer gas and the fresh air have to pass through a quantity of water maintained by the same jet at a given level in a tank, which absorbs all the poisonous elements of the gas, and then flowing over the pipe J runs away into a flushing tank, which can be used for flushing the sewers, or it may run direct into the sewer. The purified sewer gas, after being mixed with air, washed with water, and so freed from all obnoxious and dangerous elements, can be allowed to escape without the slightest risk into the outer air by means of an open grating K.

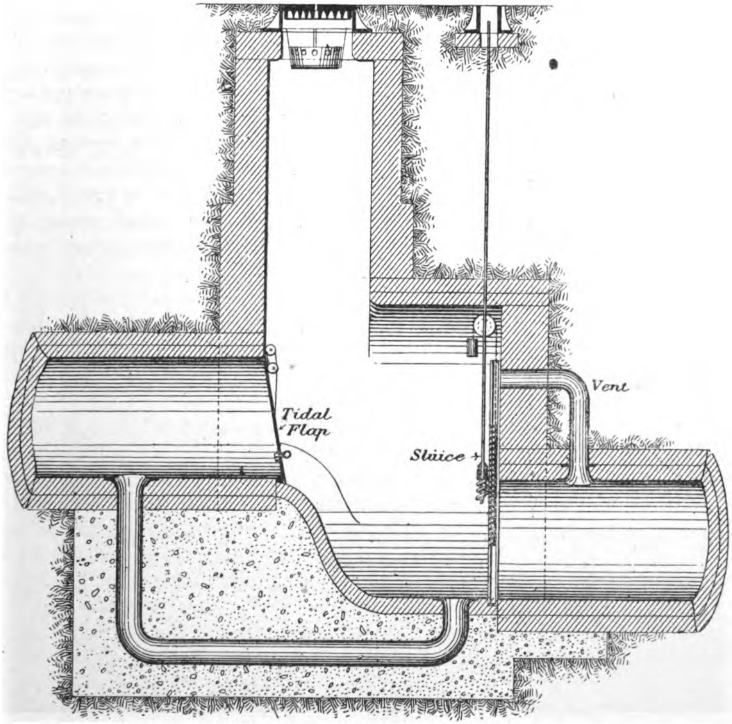


Fig. 113.—Manhole with ramp.

10,000 cubic feet of sewer gas can thus be purified at a cost of about 5s. for water consumed. It is only expected to work about four months in the year—*i.e.*, when the sewage was in an unsatisfactory condition.

193. The air in sewers will at times exert a pressure above the atmospheric pressure; it is therefore advisable to construct ventilators having direct access to the air. Manholes are not usually more than 80 yards apart.

194. Sewers with steep gradients require as much attention as those in flat districts, in order to prevent the accumulation of gases. This may be effected by placing ramps in each manhole. The incoming sewer is provided by a tidal flap, and the outgoing sewer ventilates as shown in Fig. 113. Sometimes a valve is also placed at the entrance to the outgoing sewer, which serves to regulate the velocity of the sewage, which is very desirable in very steep gradients, in order not to wear the sides of the sewer; and also, if the quantity of water passing down a small-sized sewer is comparatively little and the velocity large, the solids are sometimes left behind in the sewer. (See Art. 111.)

CHAPTER XII.

DRAINAGE AREAS.

195. In designing a scheme of sewerage for a town, the engineer in England would avail himself of a local plan of the districts, on which would be shown the buildings and streets, which would have to be brought up-to-date.

The 6-inch ordnance map for the district would give him approximately the contour levels, which are of great service for the preliminary outlines.

If he should be required to prepare a scheme for a town of which there were no plans, a survey would have to be made showing the streets and buildings, and also the lands through which it is probable the sewers would pass.

Local conditions have in most cases, however, necessitated town maps which are fairly accurate, but are sometimes only roughly so. This plan generally, then, only needs slight alterations and additions to make it serviceable. It will show, with these alterations, all that will be required to illustrate the scheme which may be proposed for adoption. Ordnance surveys are only made once in about forty years, and many changes occur during such a period, as will be seen by comparing the maps of to-day with those of the last survey. Large towns are now in existence where the maps of 1848 only show villages.

196. The levels which are marked upon the ordnance survey are not always to be relied upon. There is no doubt but that great care is taken to ensure their complete accuracy, the system of levelling being such that they can only err locally by some slip either in plotting, printing, &c.

But in coal, salt, and other mining districts, the land is subject to be lowered by the falling in of the earth in the space from which the coal, salt, &c., has been removed. Colliery owners always have a large expense in compensating farmers for the loss of crops occasioned by the land sinking and forming a basin in which the surface water lodges, and from which it cannot be removed. Railway companies have also, in some places, to keep a gang of men employed in packing the rails up in colliery districts owing to the continual subsidence. In choosing a piece of land for sewage disposal purposes, it is important to find whether it will be undermined for coal or any other purpose which would render it liable to sink. Or, if the coal, for example, has been worked, whether the subsidence has taken place. The unworked coal has sometimes to be bought in order to ensure the level of the land above.

A reasonable estimate of the subsidence of the surface of the land over a coal mine about 200 yards below would be 60 per cent. of the thickness of the seam—*e.g.*, a seam 4 feet thick after the coal has been won would probably cause a subsidence in the land equal to a depth of 2 feet 6 inches.

It will be seen from the above remarks how necessary it is to check all levels, and not to rely on any except those taken specially and for the purposes for which they may be required.

197. In preparing a sewerage scheme, contours of the surface of the district are an absolute necessity, in order to allow the drainage areas to be accurately defined. If a plot of land has been marked as a possible sewage purification area there is nothing of more importance than that the levels of every portion be accurately obtained.

In the latter case there is usually no plans showing these levels and contours; they must, therefore, be taken by the engineer; but in the laying out of the drainage areas they may be roughly determined by the contour lines shown on the 6-inch ordnance survey maps; or where these lines are not accurate enough for this purpose, the district must be contoured or such levels taken that will enable the engineer to mark out the area to be drained into any given sewer.

All streams, watercourses, and rivers should also be defined on the plans.

198. The first step in the calculations for a drainage scheme is to mark the drainage area. The sketch, Fig. 114, A, is a district which may illustrate the mode of marking out the watershed of streams. This having been done, it will at once be seen that the method applies to the drainage area of sewers. Fig. 114, A, shows a district which is contoured. The tributary streams are shown by the letters A B, F B, E B, G C, H C, J D, and K D; while the main watercourse is indicated by the letters A, B, C, D. To obtain the watershed for each stream, lines must be drawn through the ridges; D L M N D shows the watershed of the river at D; then each stream has its own watershed, which is indicated by the dot and dash lines encircling the stream—*e.g.*, the stream A P has for its area the portion indicated by the letters P M O P. Fig. 114, B, shows the same district, but it is sketched in a different manner. In order that the areas may be more easily traced the sloping sides of the hills are shown by lines which are thick at the ridges and gradually are thinned with the slope; the part not lined shows the flat portions through which the rivers and streams pass. These rivers and streams may be likened to a tree, the main branch being at D.

199. It will generally be found that there are roads which follow the rivers very closely; the main sewers would then be

Fig. 114.—Contour maps.

placed in these roads; but if the roads are much higher than the river, the sewers will be placed in the flat districts near to the river in order to drain every portion of the town; branch sewers would be run up to the roads in order to take the drainage of the houses on the roads. Otherwise the sewers may be taken up the roads and be of great depth in order to drain the lower areas; or the main will be taken up the road and intercept all drains above it, and smaller drains be run by the river edge to take those below the roadways.

If the district between C and D is of little importance, and there is more property to be drained on the line K D or J D, then a sewer could be taken through the ridge which intervenes between C and K, and continued along the line K D; or if there should only be a small drain in the latter area, it may be policy to drain it into the sewer running from C to D. If the sewage purification area should be at such a position as X, then the sewer from C could be taken direct to C and intercept that from K and J. The water from the remaining area would be that which would have to be raised by mechanical power.

200. A gravitating sewer is generally about 10 feet below the level of the road, then it will take the water from any cellars which may be on the land abutting on the road, or which may be built at some future time. At such a depth there is very little fear of the sewer being damaged by the heavy weights which may be carted over the road.

Should cellars be afterwards placed below this level, then the owners would have to provide means for lifting the sewage from it to a point that will enable it to run into the sewer, or provide a drain that may follow the sewer in the street, but join it at a lower level.

201. Suitable positions must be obtained for storm overflows. These should be placed where there is a large body of water in the stream, into which it is intended to discharge the storm water. It should also be placed so that the large body of water that is to come down the storm outlet drain will not damage or wash away the land on either side of the watercourse.

202. An examination of the lands through which the sewers are to pass should also be made in order that they may be laid in a subsoil which shall be free from water and would give a firm and solid foundation.

Every sewer should be absolutely watertight—*i.e.*, they should be so constructed that not a particle of water can get into the sewer from the subsoil. If the foundation is not of a solid character, the weight of the earth on the sewer may crack or so break the joints or material of which it may be built as not to hinder the flow, but allow a large body of subsoil water to enter and thereby considerably reduce the area of the sewer for sewage purposes.

203. The next step in the designing of the scheme is the selection

of the plot of land which is to be laid out for purification purposes. In examining the lands it may be that a suitable area will lie in such a position as will allow the sewers to have a self-cleansing velocity ; this is a very important factor, but the land itself may be ill adapted for purification purposes. Another piece may be found well adapted for land filtration, and be in such a position that the major portion of the drainage area can be drained with sewers by gravitation and with a self-cleansing velocity ; the sewage from the remaining area would have to be raised.

The Local Government Board insist now on either land being provided for filtration purposes or a certain area of what are now termed bacteria beds. The former necessitates the land being of a sandy character, which is difficult to select or obtain, and very expensive to purchase. The latter does not require any particular class of land, and may be of the roughest and cheapest kind ; there is no reason why it should not be solid clay, as the latter might be utilised in forming the sides of the beds, and so reduce the concrete or brickwork which might otherwise be required. The clay might also be excavated and burnt to form a ballast for the making of the bacteria bed.

204. If bacteriolysis is to be the process of purification, then the number of towns which have pumping stations will be reduced, as there will not then be the necessity that the land should be of such a special and expensive character. It may so happen that land could be purchased at a lower level which would reduce pumping and other expenses to such an extent that it would be economical to do away with the present sewage farms, erect bacteria beds, &c., on this new land, and probably obtain a better result than had been the case on the farm.

The level of land having been obtained, the level of the outlet must be defined, which may be the ordinary summer or the storm level of the nearest river or watercourse. The storm level of a river has an important bearing on the level of the outlet of the sewer ; the purification works should, if possible, be above it, and its effect on the inlets into the sewer directly in communication with the river should be carefully considered in order that no place should be flooded by the damming back of the water or sewage. Allowance having been made for the loss of head on passing through the purification process, the level of the sewer at the entrance to the works will be obtained.

The lines of all the sewers may now be laid down on the plans and sections, the question of the main outfall and other sewers having a self-cleansing velocity, the reasons for which, having been already enumerated (Art. 146), being paramount in the mind of the engineer in all possible cases.

205. The drainage area having been marked out for each branch and main sewer in accordance with the suggestions already made,

it may now be divided into three parts—(1) The area from which the surface water ought and must go into the streams and watercourses; (2) the area, the surface water from which it is impossible or inconvenient to drain into the watercourses; and (3) the area on which dwellings and buildings of all descriptions are erected, and from which the surface water and sewage must drain into surface water drains or sewers.

To obtain the area from which the water will drain into the watercourses, the land itself must be examined, and if it be found that a certain area drains into a course which would eventually discharge into a sewer, the course should be changed so that it may go direct into a river.

All land not available for building purposes should have its surface and under drainage diverted into watercourses having outlets into a river, and, if necessary, surface water drains should be constructed for this purpose. Every facility must be given for the water to go into surface water drains or watercourses from lands which may be very hilly, or the surface of such a character that the water from a rainstorm flows more quickly from what has been termed the " built-up " area. It is from such areas as these, if unprovided with ample outlets, that water flows with such swiftness and volume as to cause damage and floods. It is possible that an area may be so placed that it cannot but be drained into the sewers where surface water drains are not intended or constructed. Then the area must be marked as a surface drainage area, and provision must be made, in calculating the amount of water to be dealt with by the proposed sewers, for the rain water that may come from this surface.

206. The "built-up" area may be approximately calculated from the population, the latter being a quantity which must be estimated. For towns in Great Britain the population is accurately taken every decade, and there is a system of obtaining the population in almost every country. It may be fairly accurate to estimate the population by obtaining the number of inhabited houses, and multiplying this number by five. This is not, however, the population which is to be used in the calculations.

The population must be taken at what it will be 30 years hence, this being the period over which the Local Government Board will allow the repayment of a loan for the construction of the works to be spread. It is by this means that local authorities are able to carry out works not merely necessary for existing requirements, but also those of the future. As instalments are paid every year to provide the sinking fund for the repayment of the loan, it is evident that the future population who benefit by the works also assist in paying the cost.

In order to estimate the population of a town in 1930, the last three census returns must be taken, thus—

Population of town in		
1861, . .	30,000.	
1871, . .	31,800,	shows an increase of 6 per cent.
1881, . .	33,400,	,, ,, 5 ,,
1891, . .	35,100,	,, ,, 4 ,,

The increase is therefore in a decreasing ratio of 1 per cent. per decade; there may, however, be some reasonable doubt as to whether this ratio is likely to be maintained or decreased. For example, there may be intended better railway communications, which would bring out more prominently the natural advantages of the town, and a nearer acquaintanceship with the district would indicate whether new mills or manufactories, or a new trade, which may be in embryo, would cause a much greater increase, or whether a stoppage of certain trade concerns would mean a further proportionate shrinkage than the figures indicate.

Apart from these considerations, the estimated population may be taken as increasing 3 per cent. during the ten years ending 1901, 2 per cent. during the following decade, and 1 per cent. during the ten years ending 1921; this population would then be stagnant during the following ten years. The estimated population following on these calculations would in 1930 reach about 37,250.

There must now be made a plan showing how the present population is distributed, and to which area the prospective population will be allotted.

The ordnance survey map of 1848 will show approximately in which area the habitable buildings were then situated, and that of 1890 will show by comparison in which direction the erections have been built during the intermediate period. It might then be safely assumed that the prospective buildings would be in the same direction, unless the physical features of the place should prevent it. Otherwise a superficial observation of the district would indicate where the more recent buildings have been erected. The available land about a railway station would certainly be taken up for building purposes, as would also the land round and near to any manufactories; the local officials would be able to give valuable information in this respect.

207. Having estimated the population, it is necessary to form an area on which that population will stand on. Taking the average house to hold five persons, the area of the house must also be approximated in order to obtain this area, which would form the built-up area. Taking the class of houses that may be erected in accordance with the model bye-laws, the least area of a house may vary from 150 square yards, including front and back streets, to 400 yards and upwards; but houses in old towns have a much less area than the lowest just given, and there are dwellings much greater in area than the house of the larger superficial. There are towns in England very densely populated, considering the class

of buildings that are allowed to be erected; there could be pointed out several with over 90 persons to the acre, but the average does not exceed 70. That is to say, the average house has an area of about 350 square yards.

The simpler method would be to obtain the ordnance survey

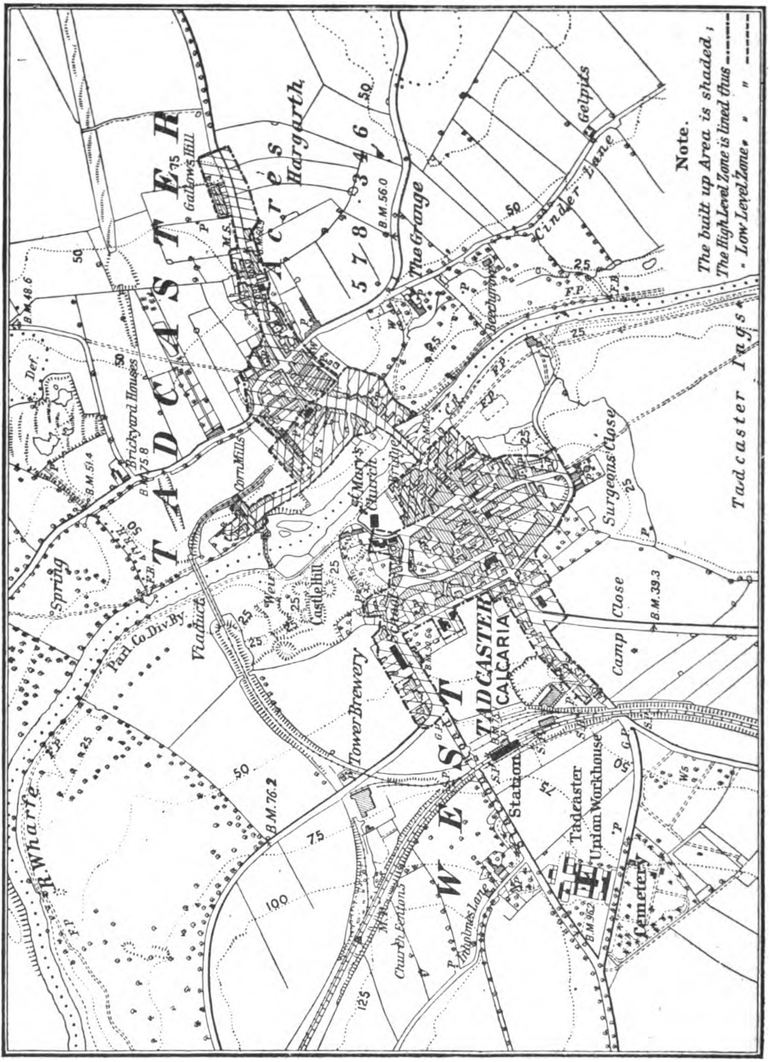


Fig. 115.—Map showing built-up areas.

map for the town and clearly mark the built-up area, which should then be computed in acres. The proportion of such acreage to the known population of the town at the period when the map was surveyed may be used for obtaining the acreage for the prospective population, after allowing for the proposed buildings a larger area of land which may be necessary owing to the difference in the bye-laws for the time being, which may necessitate a larger proportion of land to the buildings than had been the case in the previous decades.

Fig. 115 shows the map of a town, the built-up areas of which are shaded, the high level areas being surrounded by dot and dash lines, and the low level areas by dotted lines. The sewage from the latter areas has to be pumped into the sewers draining the high level zones.

208. The rate of flow of sewage per head of population varies with the towns. Gaugings show that it has an average of from 25 to 30 gallons per head per day—*e.g.*, for Durham it is about 18 gallons, for Liverpool about 27 gallons, and for Wakefield about 60 gallons (for rate of water supply see Art. 248, p. 171).

The flow of domestic sewage should not exceed 12 to 15 gallons per head, and any increase on this quantity must have its source in some other direction than dwelling-houses. Leakages in the water mains will often account for some of it. Bad joints in the sewers will allow subsoil water to pass into the sewer, in some cases to a very considerable amount. Large volumes of water have sometimes had to be turned into the sewer from such sources as springs in cellars which could not be diverted into watercourses. Manufacturers may turn their waste liquor into the sewers, and this water may be obtained from private sources or from the water supply of the town. Thus the amount of water to be dealt with as sewage is a quantity not easily defined. The volume must, therefore, be obtained by gaugings of the present outlets from manufactories which intend to turn their water into the sewers, and from the present sewers at different points, so that the quantity may be obtained from known areas. The leakages from the defective water supply ought to be rigorously stopped, and such precautions taken as will prevent subsoil water from entering any of the sewers.

The volume of sewage is a small item when compared with the volume of rain water which the sewer may have to provide for.

209. In all districts there should be provided self-registering rain gauges, which should indicate the amount of rain falling during any portion of each hour every day. They should be placed in an open space, and close to the ground surface; in hilly districts they should be placed on each hill, as the rainfall varies in intensity as the position of the hill relates to the prevailing winds. Those towns which have adopted this class of gauge have found them to be of inestimable value.

By their assistance the engineer is able to obtain the rate of fall, and also the quantity; the latter is of little value in comparison. The rate of fall and the time during which the rain fell will give the information that is desired for estimating the quantity which would affect the sewers.

To illustrate the value of the automatic self-registering gauge:—By referring to statistics, such as Symons' British Rainfall, it may be found that in a certain town on a certain day an exceptional fall of 3 inches of rain was recorded. This does not mean that 3 inches fell during the whole of the 24 hours, but in all probability during only a brief period of the day. If it was divided over the whole 24 hours, the fall would represent a very gentle but steady downpour, but if the fall was over in one hour then it represents a flood of large dimensions. Such a storm is very infrequent, probably only once in 10 or 20 years in any particular town; there are, of course, towns so situated where such rainfalls might be expected from the configuration of the landscape more frequently than in others. Thus, the rate of rainfall is greater in the Lake District than in any other portion of England.

On page 174, the storm overflows and sewers of several towns are commented upon, and it is shown how unsatisfactory is the scheme of design.

A definite rate of fall must be fixed, and the sewers made ought to be capable of dealing therewith. Generally speaking, in England, sewers which provide for removing a rainfall of from 4 to 6 inches in 24 hours are ample in size. In districts that have drains capable of delivering the water into watercourses, the capacity of such drains should be allowed for in the design of the sewers in those districts. In other countries it may be deemed advisable to provide a much greater quantity. The sewers in Buenos Ayres are of a capacity to deal with 1½ inches per hour. It will be understood that in no case should the sewers be subject to pressure.

210. The sewers, below which such a provision has been made, may be greatly reduced in dimensions by the erection of storm overflows having free outlets into the river or watercourse that may be near to the sewers. These outlets can only be obtained in some cases by traversing a considerable distance; some storm overflow sewers are even two miles in length before they obtain a free outlet. The overflow sewers will be designed to take all water from the district which the sewer at this point drains, over and above six times the daily dry weather flow from that district; the maximum flow is twice the ordinary flow; the level of the weir should therefore be such as will only allow the water in the sewer to overflow into the storm sewer outlet when it has twelve times the average flow. The sewers, then, below this point should only take the volume which does not flow into the storm overflow, and will consequently be small in comparison with the sewer above the storm overflow.

The storm overflow is the foot, so to speak, of the drainage area of the sewers above it.

Conclusions:—

(1) Mark the line of sewers on the plan, following the watercourses or lowest available roads, as indicated.

(2) Define the most suitable places for storm overflows.

(3) Define the drainage area of each storm overflow.

(4) Subdivide this drainage area for the purposes—(*a*) Area draining into watercourses direct; (*b*) area to be treated as unbuilt upon, but having to be drained into the sewers; (*c*) area to be treated as "built upon."

(5) Define the area for each branch sewer.

(6) Plot the inclination of the sewers, and with the water supply for domestic purposes given as, say, 15 gallons per head per day, the rainfall as, say, 6 inches per 24 hours on the built-up area, and half an inch for the unbuilt-upon area, the dimensions of the sewers may readily be obtained. Any manufacturers' waste liquids, and such water as from springs, &c., that have to be taken into the sewers, must be separately allowed for. Enquiries on the spot must be made in order to obtain fully the volume of such waters as these.

211. From a theoretical point of view it will be found, on working out the dimensions of the sewer, that a pipe or culvert which is to take a volume of sewage from another sewer above it is to be of smaller dimensions on account of the greater inclination that the configuration of the ground allows. When this is the case, the mouth of the smaller sewer must be shaped so that the velocity is not decreased by any sudden reduction in size. It is policy at times not to interfere with the dimension when the sewer is changing its inclination, especially if the length is slight compared with the length of the larger sewer. The expense of such a change from a constructional point of view would be inconsiderable.

212. Generally speaking, outfall sewers are flat. This is accounted for by the fact that the purification area is not very different in level from the land which is to be drained in the lower portion of the town; the sewer may be 9 or 10 feet below this level, but must have fall enough to discharge itself at such a level as will allow the water to pass through the operations required to purify it.

This means, practically, that the purification area should be, roughly speaking, 16 feet below the lowest level in the town—this depth increasing with its distance from the town, as allowance must be made for a reasonable inclination of the sewer.

A thorough knowledge of the drainage system of different towns will often give the student a greater insight into the many peculiarities which can hardly be enumerated in a work of this character. There are local considerations in every case, and each must be dealt with on its merits.

CHAPTER XIII.

SEWERS, MANHOLES, LAMPHOLES, &c.

213. **Sewers.**—The sewage from one side of a river has occasionally to be brought to the other side; usually the latter is the side which has the larger population, and consequently the larger sewers.

It is not materially cheaper to convey a small pipe across the river than a large one, because the main expense of the crossing is in providing the dams, which would be the same for a large as for a small sewer.

If the sewers are not so joined, then each side of the river would have, for the same town, its own sewage disposal area—a course which would in the majority of cases be unwise and costly.

The line joining the inverts of the sewers on each side of the river would frequently be either above or below the water-line of the river, so that if the sewer could by some means be bridged so as to follow this line it would be a hindrance to the flow of the water in the river. It is necessary, therefore, to connect both sides by means of an inverted syphon.

Fig. 116 shows a sketch of such a construction. On the north side of the river the sewer draining the area on that side is indicated, and at the end is a manhole which is marked D. On the south side the sewer A is shown, into which it is desired to discharge the sewage from D. In this case if the two sewers were joined direct, the part bridging the river would interfere with the traffic, and would also be detrimental to the flow when the river was in flood. The sewer is therefore taken under the river by cast-iron pipes. The greater the fall between the two manholes the better it will be for the cleanliness of the syphon. From manhole D there would be constructed a storm overflow discharging into the river. The pipe between the manholes D and A would be continuous, with a junction and sluice in the manhole C, as shown. The dimension of the pipe should be designed to give with its net inclination between D and A a self-cleansing velocity to the ordinary dry weather flow. But the syphon would be required to discharge rain water. Then this pipe may be slightly increased in size to take, say, three times the flow, and another laid alongside, until there is a sufficient provision for the remaining quantity to be dealt with. The latter pipe is not to come into action until the first is discharging full bore. The sluice in the chamber C is made to open at the top of the manhole only. When this is opened the water in the syphon will empty itself into the chamber (which is to be of a capacity to take the water contained in the pipes). This water, after settling, may be pumped into the sewer at D, and the sediment deposited in the chamber brought to the surface and carted away. The temporary cleaning of the pipes may be done by damming the sewage in the manhole D, and allowing it to suddenly discharge itself through the pipe. It may be thought that this method would in general be a satisfactory method of cleaning the syphon. It does not prove to be so, and it is therefore advisable that the sluice should be provided for the more efficient removal of the deposit in manhole C.

The pipe between A and C may be in one straight line, or be bent at B, as shown. In any case there should be a good fall (1 in 80) to the manhole C, in order to bring away any sludge that may have been deposited to that point.

The syphon would have to be of iron to withstand the pressure of water on it, and laid in a bed of concrete. Piles would have to be driven into the river-bed (see Art. 360) in order to prevent any flood of water undermining the pipe and lifting the syphon out of its bed.

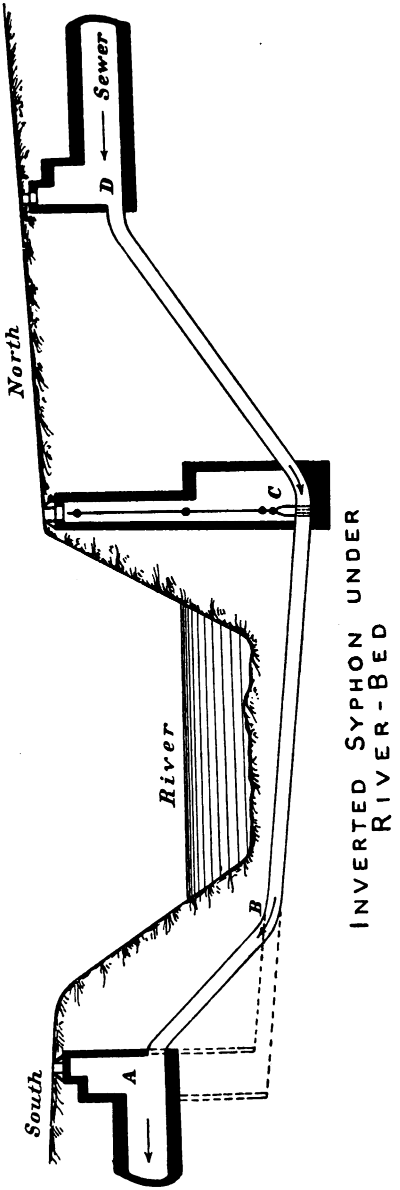
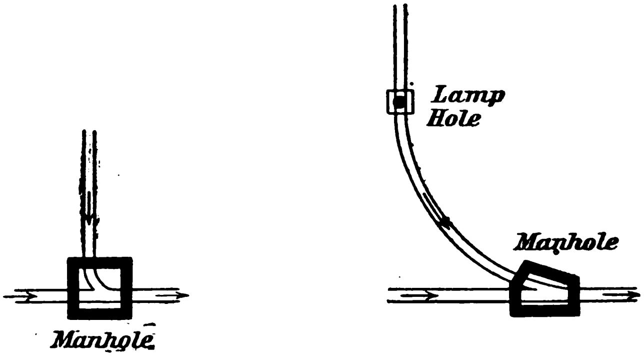


Fig. 116.—Inverted syphon under river.

In constructing such syphons under canals, great care has to be exercised that no leakage takes place from the canal into the construction.

214. When the sewers are of large dimensions and the fall is only slight—*i.e.*, not self-cleansing—the sewer at D would probably be brought forward to C. This manhole would be of sufficient dimensions to enable the workmen to carry out their duties conveniently, and the sewer under the river would be of the same size as the sewer above or below it. The bottom of the manhole A would be lowered to the level shown by the dotted lines. The sewage would then have a vertical drop at C and a vertical rise at A. A large sumph would be constructed at the bottom of the manhole C. The syphon under the river would be constructed in duplicate, in order that when one required cleaning the other might be in working order. The sewage in that which required cleaning would be pumped out, and the silt and deposit swept into the sumph, lifted to the surface, and removed to a sludge pit or disposed of on farm lands. In place of duplicating the syphon, an apparatus (such as that described in Art. 267) might be used for the removal of the deposit when the sewage is flowing.

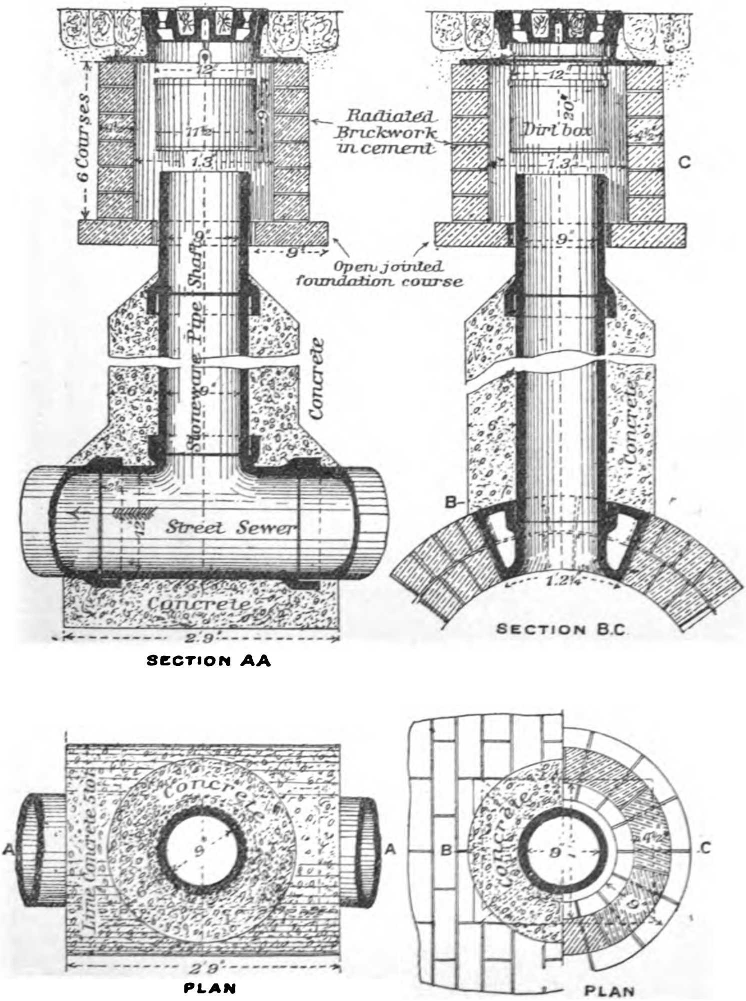


Figs. 117 and 118.—Junction manholes.

215. **Manholes and Lampholes.**—Manholes are placed at junctions of sewers and at changes of direction or inclination. They are built in order that men may go down and examine any obstruction in the sewer. The obstruction may be removed by rods, or, if the sewer be large enough, the men may enter it, bore into the obstruction, and remove it by lifting it to the surface. Shallow manholes are 5 feet 3 inches long for a height of 6 feet above the invert, arched over and reduced to 2 feet 8 inches square from 6 feet above the invert to within 14 inches from the surface of the road; a 6-inch stone landing is placed over the opening,

which forms a bed for the iron manhole cover. The landing and cover have 20-inch openings.

In deeper sewers the manholes are circular in plan—this shape being stronger, if the bricks are radiated properly, than the rectangular shafts. The thickness of the brickwork is increased with every eight feet from the surface.



SECTION AA

SECTION B.C

PLAN

PLAN

Figs. 119 and 120.—Lamphole for sewers.

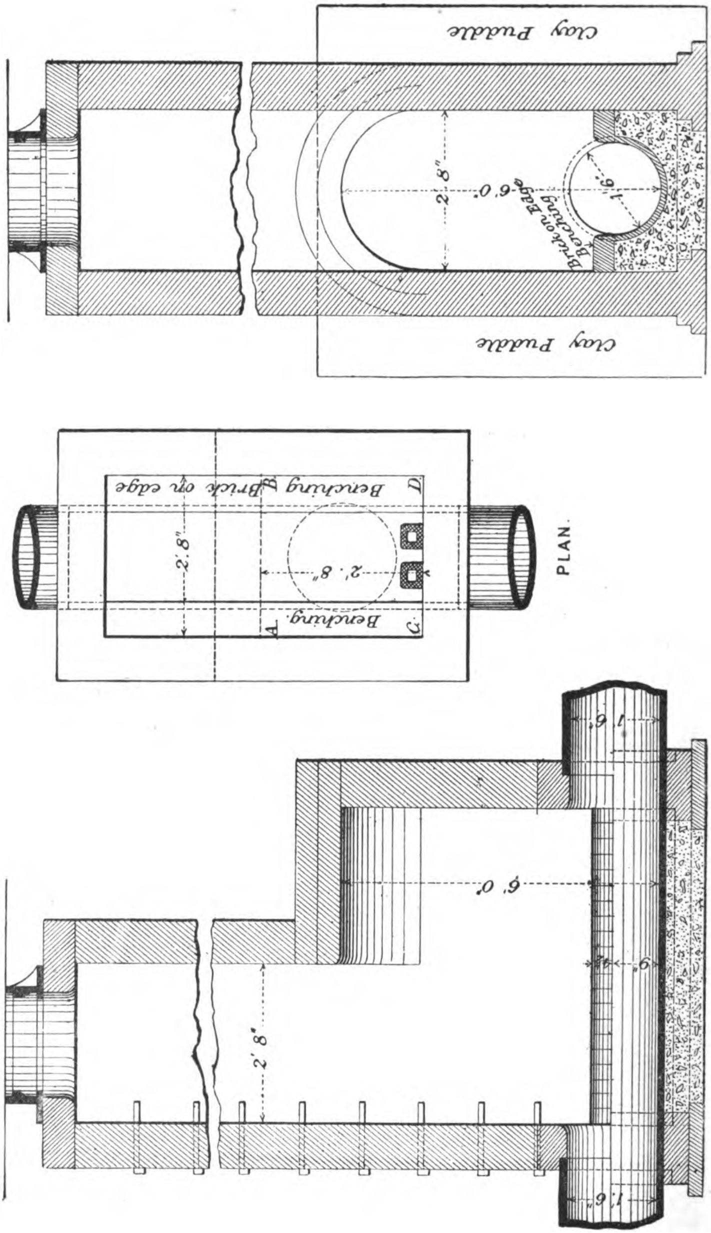


Fig. 121.—Manhole.

Junction manholes are made about 6 feet long and 4 feet 6 inches wide, as shown in Fig. 117, in order that the branch drain may be curved; the sewage may then join the main sewer in the direction of the flow. In some cases the branch drain is joined with the main sewer by a curve, as shown by Fig. 118, the radius of the curve being from 20 to 25 feet. In this case a lamphole must be placed at the end of the straight length.

216. The lamphole is simply a pipe brought vertically upwards from the top of the sewer to the surface of the road, and covered with an iron grating; the pipe shaft is 9 inches diameter, and allows a lamp to be lowered into the sewer. A man in the next manhole, which is placed about 80 yards away or at the change of direction, will then be able to see whether or not the sewer is clear.

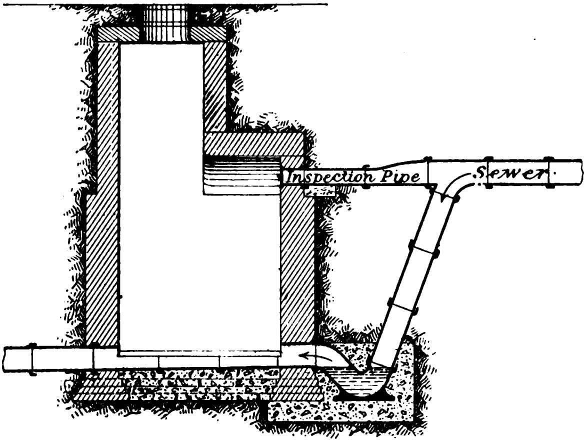


Fig. 122.—Manhole in a steep gradient.

There may be some difficulty in cleaning the curved portion if it is not constructed large enough for a man to pass through. These curved sewers are rarely built. When the branch is less in diameter than 24 inches, the manhole at the junction is built as shown, the mitre being formed with sand rubber bricks, or worked stone.

Figs. 119 and 120 show the construction of a lamphole.

Fig. 121 shows the type of manhole described above.

217. Fig. 122 shows the manhole that is usually placed in a sewer which would have too great a gradient if the invert line was straight and continuous. The pipe is brought direct into the manhole, but the sewage flows through pipes having a sudden drop on to a syphon trap, which forms a cushion to the water, and breaks its velocity as it enters the manhole. The pipe entering the manhole nearer the surface of the road is used only for cleaning purposes.

218. At seaside towns, the sewage is, as a rule, discharged without treatment direct into the sea.

To obtain an outlet for this sewage so that it is not deposited on the beach, a careful and accurate survey must be made of all the currents for a considerable distance from the coast line. These surveys must be made in all states of the tide in order to determine whether there is any variation in the direction and position of the currents under the different circumstances. It must also be ascertained whether there are two currents, one above the other.

The current which is to be the conveyor for the sewage should be such as will ensure the sewage being carried out to sea, and not be returned or deposited on the beach in any place.

It is sometimes necessary to convey the pipes a couple of miles from the beach in order to obtain this desirable result.

There are other cases where the outlet is into the sea at a point just below the low water level. In these the sewage has to be retained in a chamber during the period the tide is coming in (or, as it is technically termed, "flowing"), some 6½ hours, as the sewage cannot be discharged until it has a head equal to the height of the flood. It will therefore be seen that the sewage only flows on and during the ebb-tide. When the tide has reached its lowest ebb the flow of sewage should be automatically stopped in order that it may not be brought on to the beach with the flowing tide. If the position of the outlet at the low water level is in a current which may flow seawards during a short period of the flowing tide, the sewage may discharge also during this period.

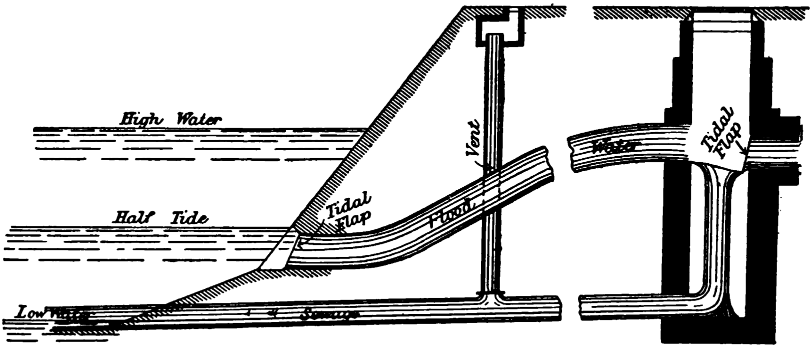


Fig. 123.—Sea water sewage outlet.

Fig. 123 is a rough sketch of a tidal outlet. At the outlet of the sewer a tidal flap is fixed which closes the sewer until the sewage in the sewer has a greater head than the tide. The flood water culvert is above the level of the invert of the sewer to ensure the ordinary flow discharging into the sea at the low water level; this culvert is also provided with a tidal flap which prevents the sea water entering the chamber and affecting the flow. On the cast-iron or steel pipe discharging into the sea at the low water level, a ventilating pipe is placed in a convenient position in order to allow the air which might collect in the pipe a free outlet, and ensure the pipes discharging full bore.

219. In place of a chamber in which to store the sewage during the flowing tide, a sewer might be constructed that the flow may be continuous. In Fig. 124, let D be the sewer from the town; at A a chamber would be constructed to hold the 6½ hours flow, but in the case about to be described the sewer discharges direct into the sea from D through A B to C. When the tide begins to flow the sewage is turned into the sewer A, E, F, G, H, and by the time it reaches B the tide is on the ebb; it is shut off at A. The sewer D A discharges as before, and when the tide is at its lowest ebb the sewer A, E, F, G, H, B has emptied itself, together with the sewage from the town during the time the tide is falling. This sewer might be made with such an inclination as would keep it self-cleansing. In any case means could easily be provided to secure it being free from deposit. The sketch illustrates the principle, not necessarily the mode of construction.

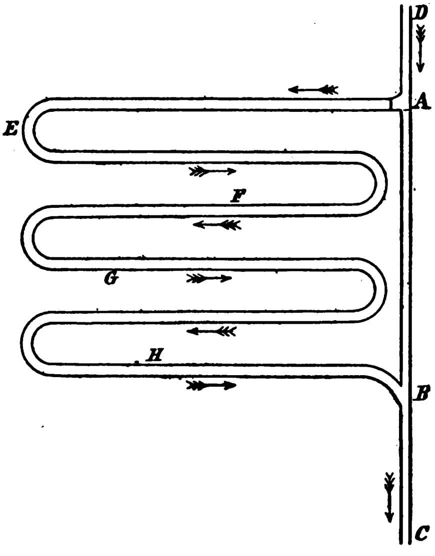


Fig. 124.—Continuous flow sewer.

Sea water acts as a protective against the deleterious effects of decomposition, but it will not prevent precipitation; therefore, if a chamber is constructed, unless special precautions are taken, the sewage deposits a considerable amount of sludge, which will frequently have to be removed.

The sewer that must provide for the backwatering should be as short as possible.

Pumping may be resorted to in those cases where the sewage is discharged during all states of the tide and the level of the sewer outlet is below the high tide.

220. *Flushing tanks* are very effective in cleaning sewers; they vary in construction, but all discharge a large bulk of water in a short space of time.

An iron gate is sometimes put across the sewer, reaching to about two-thirds of its height; the sewage is thus dammed back until it reaches the level of the top of the gate; the latter is released automatically, or a man is engaged to knock away a catch. The flood of water forces the gate open, and rushes with considerable impetus through the sewer, clearing away all obstructions through a distance which may easily be calculated.

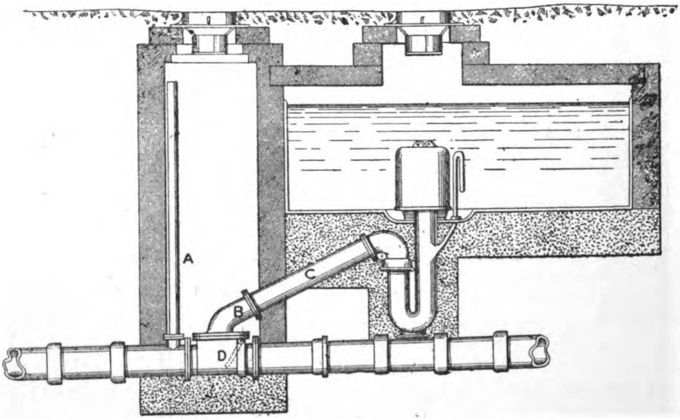


Fig. 125.—Adam's flushing syphon.

221. Enlarged manholes are occasionally constructed at the head of sewers capable of holding from 500 to 1000 gallons; this is filled (in some cases with sea water) with water, and by the lifting of a flushing gate the whole quantity is discharged at once into the sewer.

In other cases tipping gates acting automatically, as described in Arts. 43 and 44, are placed in the sewer.

222. Portable iron tanks, holding 1000 gallons, are used in several towns; they are drawn by team labour to the sewers re-

quiring flushing. At the under-side of the tank is a canvas mouth about 15 inches square, which conveys the contents of the tank to the manhole. The whole volume is discharged in a very short space of time, and if the sewer is not capable of discharging the quantity as it enters the manhole, the water backs up the manhole, and the velocity through the sewer is thereby increased.

223. Fig. 125 shows the automatic flushing tank. The tank is constructed of the required size to hold 500 to 1000 or more gallons, depending on the size of the sewer to be flushed; a flushing syphon is built in, which will discharge almost instantaneously the whole volume when it reaches a certain height in the chamber. The tank is fed by a tap which may be regulated to any speed. The syphon acts if the feed water only enters the tank in drops. A is a ventilating shaft, B and C are the pipes which deliver the water from the tank into the sewer, and at D is placed a tidal flap valve to prevent the water from flowing against the fall of the sewer.

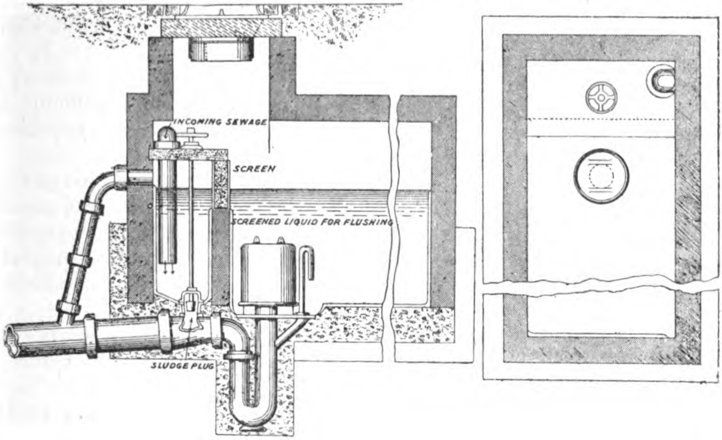


Fig. 126.—Adam's flushing tank.

224. Fig. 126 shows a similar method of flushing a sewer, but, in place of using a fresh water supply, the sewage from another sewer may be turned into the chamber. No solid matter is allowed to enter the syphon. Occasionally the sludge that may be deposited in the small side chamber is turned into the sewer by means of the plug shown in the sketch just before a flush is sent down.

CHAPTER XIV.

TRADE REFUSE AND RIVER POLLUTION.

225. In designing a scheme of sewerage, one of the preliminary inquiries must have reference to whether trade refuse is, or is not, to be allowed to enter the sewers. This is a matter which must be settled by the local authority; it is also a problem on which the advice of the engineer may be asked.

The question is important, not only because the treatment of the sewage at the outfall works is rendered more difficult by its admission to the sewers, but also because it may require a material increase in the dimensions of the sewers.

In many towns fishmongers, greengrocers, &c., are charged 2s. and 2s. 6d. per load for their offal to be removed and disposed of by the Corporation. Should manufacturers refuse to be dealt with on similar terms, these tradesmen would naturally complain. There is no comparison obviously between the cases, but the fact remains that such complaints have been made.

226. The tendency is to prohibit trade refuse from entering the sewers. This is insisted upon, because in some cases the refuse is of such a character as to eat away the brickwork; in other cases the depositing material is so great as to be detrimental to the working of the sewer; there are also waste liquors giving off such very strong, offensive, objectionable, and possibly dangerous odours, that it is undesirable for them to enter the sewers on this ground alone.

227. It may appear to be difficult to settle what liquors may and may not discharge into the sewers. It is perhaps less difficult to determine the state of the refuse before it is allowed to enter the sewer—*i.e.*, the temperature, amount of deposit, acidity, alkalinity, and volume.

228. It is desirable that no chemicals should be allowed to flow into the sewers. Manufacturers could, in many cases, recover certain metals and acids which might repay them the trouble of recovery. If the bacteriological treatment is in operation at the sewage works, such chemicals as the compounds of iron, chlorine, &c., are detrimental to the action of the micro-organisms, as they are sterilizers. There is not much objection to many chemicals if they are not either too strongly acid or alkaline. Certainly those liquors should be debarred entrance in such a state as would be detrimental to the construction of the sewer. Also the liquors

which have a large amount of depositing material should not be allowed without this deposit being first removed. Woollen manufacturers were in the habit of allowing the wool-scouring water to discharge into the sewers; in many cases it was discharged into the rivers without treatment, but it is now the custom to first extract the grease, which is afterwards sold at a profitable rate.

229. Manufacturers insist that their waste liquors should be discharged into the sewers, their reason being that they pay much heavier rates in proportion than the shops in the town; that if it were not for the mills the town would be insignificant in importance, for the trade which is introduced brings in a larger number of people than would otherwise be the case. Also that in some towns the waste liquors are treated by the local authorities or are allowed to run into the rivers, and they gain thereby an unfair advantage over those who have to treat the refuse at their own cost. They admit that the refuse must be dealt with, but think that they who assist in making it should also assist in the cost of the purification.

Some manufacturers find it difficult to keep the mills working on account of competition and the difficulty of getting material at such a price as will give some profit to themselves after it is manufactured, and when the treatment of refuse is insisted upon it is increasing the burden, which may mean the stoppage of works altogether.

That there are difficulties is apparent to the Local Government Board, who merely point out to the local authority the advisability of considering the question.

230. Certain mills are some distance from any watercourse or river, and in consequence a very large proportion of comparatively clean water is discharged into the sewers—*e.g.*, condensing water, refrigerator water from breweries, and the waste water from malt kilns. At Leicester about one-fifth of the total daily flow of sewage was comparatively clean waste water from business premises.

This class of water should be turned into the nearest watercourse by special drains, as the sewers on a combined system will have quite enough rain water to deal with without having a continuous supply of this character.

The author, in gauging the flow of waste liquors from some half-dozen works which would have to be dealt with in a sewerage scheme, found the rate of flow from one mill during certain hours of the day to be greater than the whole flow of sewage from the remainder of the town, which included mills of all descriptions. Here the water was taken from the river, and after passing through certain processes was put back in a very much worse condition than before. The others were almost similar. The rate of flow did not, of course, continue throughout the day.

The treating of this waste liquor would be quite as difficult as treating the sewage of the town, and the cost of pumping during the time this water was running would be very greatly increased, especially if it was being discharged at the same time as the maximum flow of the sewage.

231. One suggestion that has been put forward was to regulate the quantity of water to be taken from any mill, whatever it may be, by fixing a certain number of gallons per acre as the maximum that would be treated free of cost, all material in suspension to be removed, and acids which may prove detrimental to the sewers or works not to be allowed into the sewers on any consideration. Any greater quantity than this should be paid for at a rate per gallon which would be equal to the cost per gallon for treating the whole of the sewage at the disposal works. Also, that the cost of the extra size of the sewer necessary for such extra quantity should be paid for by the manufacturers.

232. It would, perhaps, in some cases be advisable and less costly to lay separate conduits which would convey the refuse of these manufactories to a special plot of land, and there treat the liquid on lines of a special nature, the cost or part-cost of such treatment being made a special tax on the owners.

233. The waste liquors from manufactories is sometimes of such a nature that the sewage with which it is mixed cannot be purified by the ordinary means, and when it is a hindrance generally to the sewage it should be debarred from the sewers.

The treatment of domestic sewage is of a simple character, but that of sewage in which there is a large amount and variety of trade refuse has been, up to now, a very complex affair.

234. In any case, if the refuse is to be allowed into the sewers, the quantity to be discharged should be proportioned over the whole of the day, and it should not be allowed to enter so that at times it may occupy a large section of or the full capacity of the sewers. If this method was adopted, the manufacturers would have to provide a tank to hold the water, and the deposit would subside there to a great extent, which would have to be dealt with at their own expense.

235. The Local Government Board have not issued definite regulations relating to the flow of sewage, trade refuse, and rain water on to the outfall works, but from inquiries it has been found that where trade refuse is to enter with the sewage the quantity of such refuse should be gauged and added to the domestic flow of sewage. The total amount to be provided for is equal to 6·6 times this total, whereas if the trade refuse is refused the volume need only be six times the ordinary dry weather flow.

236. In 1865 a Royal Commission was appointed to inquire into the pollution of rivers. Their report was issued and published two years later. It is there stated that hundreds of thousands of

tons of ashes, slag, cinders from steam boilers, furnaces, ironworks, and domestic fires, are being passed into the rivers Aire and Calder in Yorkshire, that these rivers are the receptacles for broken pottery and worn-out utensils of metal, refuse brick from brickyards and old buildings, earth, lime, clay from quarries, and road scrapings, &c., as also for spent dyewood and other solids in the treatment of worsted and woollens. Hundreds of carcases of animals—cats, dogs, pigs, &c.—are allowed to float and pollute the banks; also, they receive millions of gallons per day of polluted water from chemical works, dyeworks, scouring and fulling worsted and woollen stuffs, skin cleansing and tanning, slaughter-house refuse, and the sewage of towns and houses.

The offensive matter from dyeworks was deposited on the beds and banks, which, in times of flood, is stirred up to poison the lower reaches, acting as the navigable parts.

It was as a consequence of the report of this Commission that the Rivers Pollution Prevention Act of 1876 was passed. This is a quarter of a century ago, and the rivers remain to-day, to a greater or less degree, very much in the same condition as they did at that time. Any person examining these rivers would unhesitatingly give this as his opinion.

It would appear, then, that this Act has been of no value, or the persons to whom was given the power to put the Act in operation did not care to use it, for the reason probably that they themselves were the chief offenders.

That the Act had been allowed to pass into a state of inaction is evident from the fact that the Thames Conservancy Board is in existence, that only a few years ago the necessity arose for the inauguration of the West Riding Rivers Board, the Mersey and Irwell Joint Committee, and the Ribble Conservancy Board. Their powers are embodied in the Rivers Pollution Prevention Act already mentioned, being thus the same as those which have been in force before, but had not been enforced.

The Thames Conservancy Board has been in existence many years, but it was in 1888 that power was given to County Councils to enforce the provisions of the Act, and power was further given to the Local Government Board to form these joint committees which should have the power of a sanitary authority over the rivers and of the refuse or waters that entered them. From this date several Boards or Committees, already enumerated, have sprung into existence, and, as a result, more sewerage schemes have been presented to the Local Government Board in the last few years than have ever been before. Manufacturers have also had to purify their effluents in many cases. The work of purification of the rivers has as yet only commenced; it will be many years before it may be said that fish are to be found in the river

Calder, although such has truly been the case within the memory of the present generation.

237. These Boards have found that the powers of the River Pollution Act, 1876, were not strict enough, and, in consequence, further powers have been sought for and obtained. For example, it was found that the length of time given to local authorities to develop their sewerage schemes could be indefinitely postponed. In those districts where these Boards operate, they are now able to fix a time when the works shall be completed; they have power to extend the time should the circumstances warrant it, but if the local authority or manufacturer has not a sufficient reason for the delay in the opinion of a judge of a court of justice, a heavy penalty can be imposed.

There are many provisions in the jurisdiction of these authorities which it would be well that sanitary engineers and local authorities in that area should be thoroughly cognisant of.

238. The Local Government Board will sanction a scheme of sewerage which provides that the sewers shall be capable at all times of discharging on to the sewage disposal works a volume equal to six times the rate of the average dry weather flow, but where trade refuse forms a part of the flow this standard is increased. (See Arts. 235 and 324.) It may therefore be concluded that, if the sewage in sewers is more diluted than this, it will be allowed to be discharged into watercourses without treatment.

The rivers through a town which is sewered on the combined system will be less liable to contamination than those which flow through a town having a "separate" system of sewerage.

Should a sewerage scheme be prepared which provided separate drains for discharging surface water from every area, roof, and yard, back and front street, into convenient watercourses, it would, if submitted to the Local Government Board, be in all probability disapproved, as the recent requirements suggest that, for a separate system, the amount to flow on to the outfall works is the same as for a combined system—viz., six times the average dry weather rate of flow. As the flow of sewage in a separate system must be practically constant during certain fixed hours in each day, the excess must come from rain water, and therefore provision must be made to drain into the sewers a proportion of the areas on which rain water will fall. Should a separate system be attempted, there is the difficulty of preventing householders from discharging their washing and other large bodies of water into those gullies connected with the surface water drains. Probably the persons who have water-rights in the rivers would be better satisfied if the separate system in its entirety was actually carried out. But the carrying out of this scheme entails the subsequent pollution of the river by every rainfall, as will be shown later.

239. A well-paved, hard, impervious road, from a sanitary point of view, is not a desirable condition, unless frequently cleaned by water. It has been frequently stated that the dust and odours from such a roadway are very offensive to both the eyes and the nose, the fumes of ammonia from the horse and other manure that cannot be swept off being particularly offensive. The manure in the joints and what is trodden on to the surface of the pavement can only be carried away by a heavy downpour of rain to the gullies, and from thence into the river; in the course of a rainfall, if the air is contaminated with offensive gases, the water will no doubt carry a portion of this down in solution; then the roofs are covered with soot which must be washed away into the drains. The sewers themselves, as has already been stated, are also cleansed, which necessitates the sewage being so much stronger.

240. The following analyses have been taken, which in themselves give very interesting information :—

Sewer with *Sharp* Gradient.	Parts per 100,000.				Ratio of Total Mineral to Total Organic Solids.
	Dissolved Solids.		Suspended Solids.		
	Mineral.	Organic.	Mineral.	Organic.	
Normal sewage, . . .	30	40	7	14	0·7 to 1
,, . . .	36	50	9	19	0·6 ,, 1
,, . . .	40	29	4	11	1·1 ,, 1
Storm after first 10 minutes,	21	9	40	5	4·3 ,, 1
,, second ,,	19	5	21	3	5·0 ,, 1
,, third ,,	14	2	7	1	7·0 ,, 1
Sewer with *Flat* Gradient.					
Storm after first 10 minutes,	39	15	30	22	2·0 to 1
,, second ,,	27	9	14	5	3·0 ,, 1
,, third ,,	19	5	14	3	4·0 ,, 1

The above sample of sewage is not from a town having manufacturing works, as the following analysis will show :—

	Parts per 100,000.									Ratio of total mineral to total organic solids.
	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Oxygen absorbed in 15 mins., 80° C.	Oxygen absorbed in 3 hours, 80° C.	Dissolved Solids.		Suspended Solids.		
						Mineral.	Organic.	Mineral.	Organic.	
Normal Sewage,	30·1	5·0	4·0	6·2	12	94·2	38·0	3·0	8·8	2·1 to 1

241. The analyses themselves show that the storm was of a severe character; this will be seen from the quantity of organic matter in the normal sewage, which has an average of 54·3 parts per

100,000, which has been reduced in ten minutes to 14 parts; the storm water will evidently bring a quantity of suspended organic matter, as there are 22 parts in the flat-graded sewer after the first ten minutes of the storm, a larger quantity than appears in the normal flow, and a similar higher amount would appear in the flow in the sharp-graded sewer, but it will have disappeared in a shorter time; an analysis at five minutes after would have been interesting. To obtain the dilution shown after the first ten minutes would therefore require a large mass of clean water to be mixed with the sewage and the organic matter from streets, yards, roofs, &c. There is a larger quantity of solids in the sewer with the flat than in that with the sharp gradient. This would be expected, as the solids would get away faster in the latter than in the former. There is also an increase in the organic matter in the flat sewer; where the sewer has but a slight gradient, the surfaces of the roadways, &c., might be expected to be flat, and therefore the organic matter would come slowly to the sewer, the sewer itself is likely to be foul, and the storm water has perhaps assisted in cleansing it. The average amount of organic matter after half an hour's flow is, for the sewer with a sharp gradient, equal to 2·1 grains per gallon, while the flat-graded sewer gives a quantity averaging 5·6 grains per gallon, or an average of 3·85 grains per gallon for both flat and sharply inclined sewers.

242. We may take the sewage from a water-closeted town as a normal sewage—*i.e.*, normal as regards dilution—and we may so regard it because all water and excreta enter the sewerage system. It will not affect the size of the sewer if the closet system is that of waste water-closets, pails, or middens, as the water used for domestic purposes will eventually enter and be required to enter the drains. The sewage from such a town itself is, if anything, stronger than the sewage from a water-closeted system, as the slops from sinks, &c., urine from stables, cow-houses, slaughter-houses, the overflow and soakage from middens, &c., will enter the drains, and in some towns the contents of pails are emptied into tank carts, which are discharged into the sewers, and flushed with the sewage in the sewer, or by water from the mains; the dilution is not and cannot be the same as would occur when the excreta enters with the addition of that water which comes from the cisterns over water-closets.

243. In England the quantity of water used for domestic purposes varies very greatly, being from 12 gallons per head per day upwards. In America the quantity is from 25 to 125 gallons per head per day; so great is the quantity of water used in that country compared with the domestic refuse, that in some cases the sewage is turned into the canals without treatment.

In a non-manufacturing town the quantity of water used for domestic purposes per head per day would be about 15 gallons;

therefore, if 75 gallons of water are added, the sewage is increased in volume six times. It will be noticed that the average rate is considered. Should a storm overflow weir be placed at the level, which would take any water flowing above the rate of 90 gallons per head per day, the actual state would be that the dilution of the sewage flowing into the river would at some hours of the day be greatly reduced—*e.g.*, the maximum flow is at the rate of 31·5 gallons per head per day, the dilution would therefore be only 2·8 : 1; on the other hand, at other parts of the day, when the minimum rate was flowing, the dilution would be increased to about 23 to 1.

A sewage, if diluted to any greater extent, it may be taken, would be allowed by the Local Government Board to run direct into the rivers without treatment. If there should be manufacturers' refuse included in the sewage, then the amount of water must be increased by 10 per cent., making the dilution equal to 5·6 to 1, when the dilution is greater than this it is allowed to run into a watercourse. Sewage in a diluted state, equal to 5·6 of water to 1 of sewage or less, must be treated at the sewage disposal works. There will probably be definite regulations on these matters issued by the Local Government Board when the Royal Commission now sitting has presented its report to Parliament.

This state of dilution would not be allowed if the water in the river was to be used for drinking purposes, or where a higher proportion is required for other objects. All the pathogenic germs, solid matter, &c., would have first to be eliminated. A few years ago sewage was allowed to run into the river which supplied Hamburg and Altona with drinking water. The towns were greatly depopulated with the ravages of disease which was spread by the use of this water.

Certain chemists say that if there be as little as 0·002 grain per gallon of albuminoid ammonia in water, it would be unsuitable for drinking purposes.

Bacteriologists tell us that it is not so important if there should be a little albuminoid ammonia in potable water, that in all rivers this albuminoid ammonia must be present in some small degree from the manure of the cattle on the fields abutting on the river, and from the manure that is often put on to the lands as a fertiliser.

They maintain that it is the presence of micro-organisms which renders the water unfit for domestic purposes, and that these should not be in number more than 25 per cubic centimetre. They further notice that it matters little how many organisms there may be, as the important point to be determined is the presence of any capable of producing injury or disease.

From these remarks it will be apparent that bacteriologists must be employed to determine the state of the river that would be allowable at any fixed point after sewage had been admitted. Glasgow and Bradford have such a person now in their employ, and there is no doubt that the engineer who may take up the study will find it of great service.

244. A river is a purifying agent in itself; some rivers do not act so well as others, as the action depends greatly on the depth, velocity, geographical position, and physical condition of the river.

It acts (1) by oxidation from the atmospheric oxygen.
„ (2) by natural deposition.
„ (3) by the action of micro-organisms.

The first depends on the peculiarities of the stream, as the more the water is aerated the greater will be the oxidation; hence weirs, rapids, and falls favour purification.

It is desirable that the process of purification depending on deposition should not be encouraged, especially on sluggish rivers, and those that are locked for canal purposes.

The non-putrefactive organisms require a large amount of oxygen to retain their working capabilities; the quantity of oxygen depends on the absorbing power of the river, a good river water containing 6 to 8 volumes per thousand. The action of these organisms also depends on the opportunities which the atmosphere has of obtaining access to the organic matter.

At the bottom of a deep river we may consequently find the putrefactive organisms to be very large in number compared with those found in water at or near to the surface.

The Massachusetts Board of Health arrived at the conclusion that (the unit of population being 1000, and the volume being in cubic feet per second) volumes of from 2·5 to 7 cubic feet per second per unit of population, containing 0·1116 to 0·0399 part of organic matter per 100,000, should be regarded with suspicion, and that with volumes less than this the pollution should be avoided.

Mr. Adeney, F.I.C., found that when filtered sewage was mixed with water from the River Vastry in the proportion of $\frac{1}{99}$, $\frac{1}{89}$, and $\frac{1}{79}$ there was no putrefaction, at volumes $\frac{1}{69}$ and $\frac{1}{59}$, part of the oxygen in the river water was unabsorbed, and at $\frac{1}{39}$ the oxygen was absorbed and all the organic matter was oxidised. In volumes less than this the putrefaction commenced.

Dr. Tidy found that light flocculent matter was the last to subside and the first to putrefy.

245. It seems, then, the Local Government Board, in fixing the quantity that may go into the river at six times the flow, are giving engineers a very simple method of defining the position of the weir of a storm overflow, but it is questionable whether the storm water so flowing will have a putrefactive effect on the river, or whether the river would purify the storm water. The quantity of water

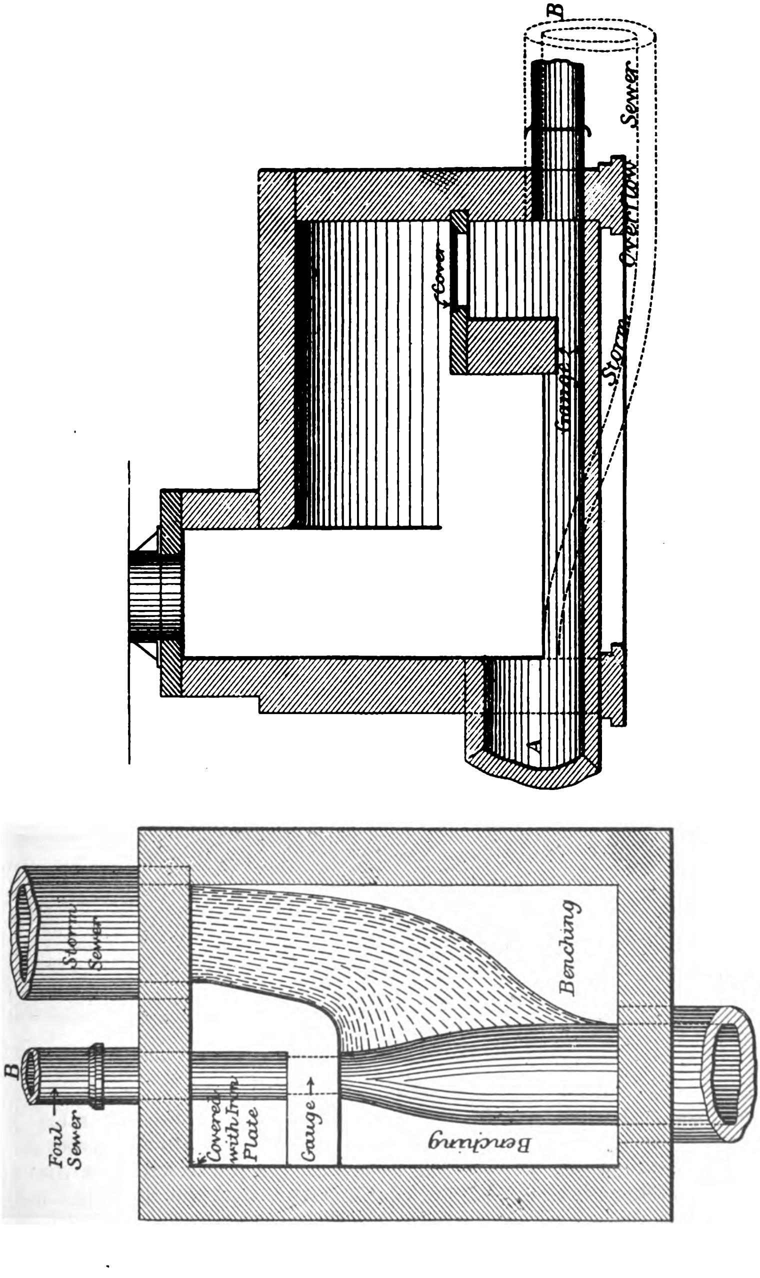


Fig. 127.—Storm overflow.

in the river into which the storm overflow is to be discharged ought to be a minimum for a certain quantity of water from the storm overflow. It may be considered a difficult matter to say what the quantity of water will be in the river when the storm overflow will work, but it must be acknowledged that the storm will not make much increase in the river at the time the storm overflow will work, because the water in the sewer will flow very much quicker than it can do in the river, and the flood in the

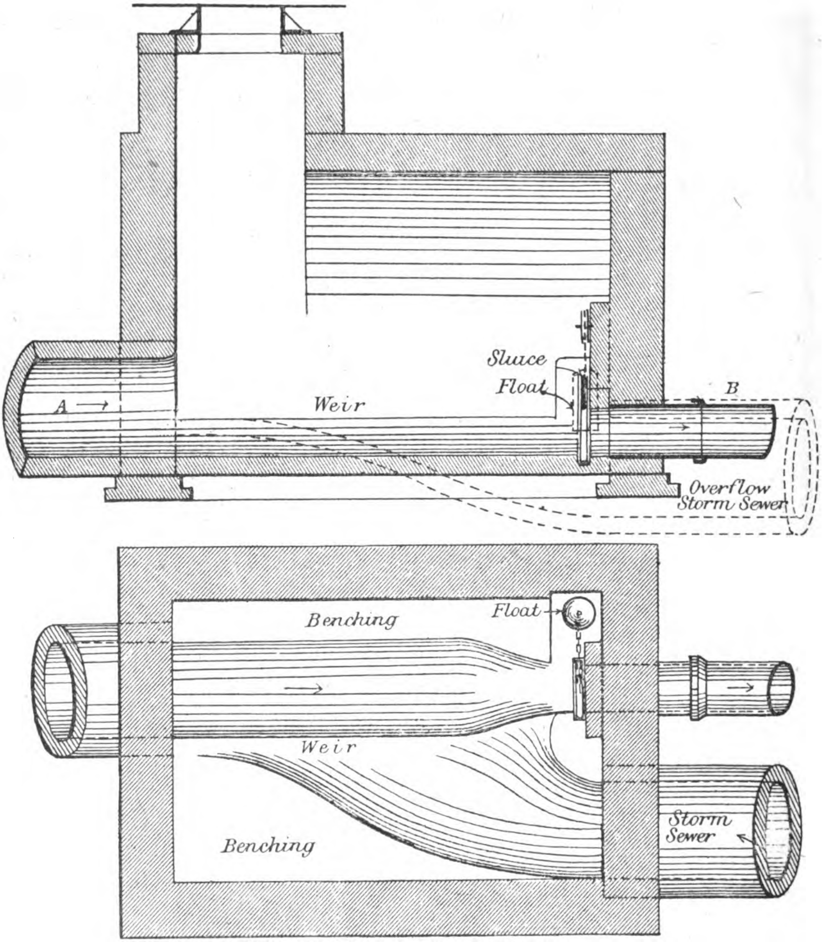


Fig. 128.—Storm overflow.

sewer would probably be over before the storm in the river reached the position of the storm overflow. It might therefore be taken that the normal flow in the river should be the certain fixed minimum.

246. The manner of separating the storm water so that it may flow into the storm sewer, and from thence into a river course, may be dealt with in the manner shown in Figs. 127 and 128. The sewer A is that from the district above the storm overflow. The sewer B is that draining 6 or 6·6 times the rate of the daily dry weather flow from that area. Immediately above the entrance to the latter sewer is a gauge which will just allow the quantity mentioned to pass into the sewer B; the wall above the gauge will prevent any excessive quantity from entering the sewer, and the remainder is obliged to pass over the weir into the storm sewer. In this storm overflow chamber the sewer B will always discharge a proportion of the sewage and storm water.

In order to prevent the water from entering the sewer after it has reached the stage of dilution at which it may be allowed to enter the storm sewer, a floating valve may be fixed over the sewer B, as shown by Fig. 128. The valve is open when the normal flow is being discharged; when, however, six times the flow reaches the float, the valve begins to act, and is fully closed when the water reaches a height equal to that of the valve.

This scheme has been refused by the Local Government Board, but it is difficult to understand the reason when the parabolic leap weir is allowed.

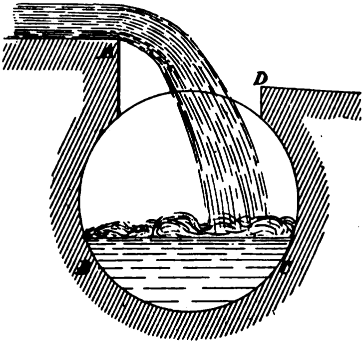


Fig. 129.—Parabolic leap weir.

247. The Parabolic Leap Weir (Fig. 129) has been adopted in some cases where there is a sufficient fall. This form of weir is used on the catchment area of a waterworks scheme, the object being to collect that water containing a large amount of sediment and wreckage which comes off the hillside with the first rush of a storm, and might otherwise cause considerable expense in keeping the catchwater clear. The water thus obtained flows over the point D, and is discharged further down the hillside. When the water is clearer, and has a lesser velocity, it flows into the chamber A, B, C, D, and from thence into the reservoir.

The principle of the weir is described more fully in Art. 45, but it will be at once seen that the point D should be at such a level and position that all the water up to six times the flow should enter the chamber A, B, C, D, and when the water increased to a greater extent it should flow over the lip D and into the storm sewer.

248. The following article is taken from *The Engineer* for Nov. 12, 1897, and is included here, as it was drawn up while gathering together the material for this work. There is considerable matter here which would otherwise have been included in the text. The paragraphs under their different headings should therefore be read in conjunction with the same subjects, which are to be found elsewhere:—

SOME CONSIDERATIONS ON THE DESIGNS OF TOWN SEWERAGE SCHEMES.

By FRANCIS WOOD, Assoc. M. Inst. C.E., F.G.S.

THE design of sewerage and sewage disposal works has reached a point just past what may be termed its "infancy stage." Generally speaking, there is a marked improvement in the sanitary conditions of our towns; and no doubt the Local Government Board, together with the various River Conservancy Boards, are at present the instigators in this improvement. As a consequence of the influence of these very active Boards, our rivers will show a marked difference from their present attributes. The perfecting of the sanitary conditions of towns has been and is a slow process, and the purification of our rivers will also be a slow process. The improvements in sewerage scheme design have been very slight; on the other hand, the design of sewage disposal works has had a large amount of attention; these works have been to a great degree in the hands of chemists, and engineers have designed this portion of the scheme to suit the ideas of chemists and the vagaries of their analyses; but the general result of the works now in operation is very doubtful. In matters relating to the works above the sewage outfall, the engineer has it practically all his own way.

A student may examine almost every text-book that exists on sewerage or sanitary engineering, and he will be nearly as far as if he had never read them from forming a definite idea as to the fundamental laws or rules that he must adopt to carry a sewerage scheme to a definite conclusion.

There are many points which require elucidation, and after examining copies of reports of schemes for individual towns which occasionally are issued to the public, I have found that these points are still matters of conjecture, and if anything really original is described it has reference to a constructional difficulty. In design most schemes are drawn up on the "combined system," with an occasional small district in some towns given over to the "separate system." These two systems with the pneumatic system are the classes into which sewerage schemes may be divided. The pneumatic system is in reality the separate system, compressed air being used—in preference to steam or the hydraulic transmission of power—to raise the sewage from a low to a higher level; and in order to reduce the cost of providing power, the smallest amount of water is allowed to enter the ejectors; this, of course, is the sewage proper. Although the rivers in England are fairly numerous and the water apparently available, I have only noticed one scheme which provided for the use of water as power to lift the sewage, and this scheme is of very recent date.

It is here my intention to bring the bases on which sewerage schemes are designed, together with a brief note on the combined *versus* the separate systems, before engineers for their fuller consideration. The bases referred to are the quantity of water per head of population, and the rainfall.

Quantity per head of population.—The water supply per head of population, according to reports that have been published, is as follows:—

England.	
Glasgow,	50 gallons.
Edinburgh,	40 ,,
Exeter,	38 ,,
London,	33 ,,
Brighton,	33 ,,
Torquay,	30 ,,
Chester,	28 ,,
Liverpool,	26 ,,
Bradford,	25 ,,
Scarborough,	23 ,,
Birmingham,	22 ,,
Manchester,	22 ,,
St. Helens,	20 ,,
Wakefield,	20 ,,
Bath,	20 ,,
Leamington,	19 ,,
Nottingham,	18 ,,
Durham,	15 ,,

America.	
Washington,	125 gallons.
Chicago,	120 ,,
Springfield,	88 ,,
Philadelphia,	80 ,,
Holyoke,	80 ,,
Boston,	65 ,,
St. Louis,	64 ,,
Lowell,	63 ,,
Lawrence,	57 ,,
Worcester,	56 ,,
Cambridge,	55 ,,
New York,	55 ,,
Lynn,	45 ,,
Fall River,	26 ,,

It does not here concern us to reason why in America they use such a vast quantity of water compared with what is used in England. It is well, however, to note the facts.

It has been stated by Mr. Hawkesley, the well-known authority on waterworks, that the quantity for a residential population is at the rate of 15 gallons per head per day. This statement is confirmed in the recent *Proceedings* of the British Waterworks Association. From these authorities this ought to be a very fair approximation. In all probability the quantity is even less if the supply be well attended to, and leakages are stopped immediately they occur. But in manufacturing towns the quantity will be increased to much more than 15 gallons. Take the case of a manufacturing town where the water supply per head is known, and gauge the quantity of sewage that issues from the outfall sewer from a definite population. The quantity per head is very greatly increased, and the reason is not far to seek. Manufacturers require water, and will obtain it from that source which entails least expense, the water being equally good in all cases for their purposes. Consequently they sink wells, and pump from these, or from the nearest watercourse. If in the passing of this water through their works it becomes fouled or discoloured, it is not returned to the river or watercourse, which procedure would render these waters unfit for use at the factories lower down the valley, but is instead turned into the sewers. In a case known to me the water supply is at the rate of 20 gallons per head; whereas the sewage discharge is at the rate of 60 gallons, and mainly from the above cause. There are also other sources which assist in increasing the discharge at a sewage outfall. In some towns, in the cellars of houses, and also in the streets, springs have been tapped, and as there is no other source to turn them into, free use has been made of the sewer. Again, small watercourses have been covered over and converted into sewers, the land drainage still running in the sewer so constructed.

From a table containing particulars of 41 towns, I find that in—

(*a*)	3	towns	the quantity per head	ranges	between	15	and	20	gals.
(*b*)	4	,,	,,	,,	,,	20	,,	25	,,
(*c*)	13	,,	,,	,,	,,	25	,,	30	,,
(*d*)	5	,,	,,	,,	,,	30	,,	35	,,
(*e*)	7	,,	,,	,,	,,	35	,,	40	,,
(*f*)	2	,,	,,	,,	,,	40	,,	50	,,
(*g*)	2	,,	,,	,,	,,	50	,,	60	,,
(*h*)	3	,,	,,	,,	,,	60	,,	70	,,
(*i*)	1	,,	,,	,,	,,	—	,,	75	,,

What reliance is to be placed on the figures it is difficult to say, as the quantity of sewage was approximate in every case and in bulk as "average flow per day," and the population was taken from the last census or estimated for the whole town. One-half of each town might have wet middens or pail closets, which would increase the number of gallons per head of population. As an example of the apparent inaccuracy of the figures, Edinburgh has a population of 265,000, and the flow of sewage is given as only 3,000,000 gallons per day, or at the rate of about 12 gallons per head, whereas the water supply is given as being 40 gallons per head. Hereford has a population of 20,000, and the flow of sewage is at the rate of 75 gallons per head; there are no manufactories. At Chester there is a flow of 62 gallons per head, and in this city there are also no manufactories. In towns where there may be no manufacturers' refuse and the quantity of sewage discharged from the outfall is very large, one naturally must think that there is a great waste from the water supply, or that a very large quantity of subsoil water finds its way into the sewers.

There appears to be a great dearth of trustworthy information regarding this question, and the sooner engineers look into the matter the more certain they will be in their ideas and schemes. It is admittedly a difficult question to settle permanently; but as it is very important, it appears to me that sewers from houses in a residential district should be of a size to cope with 18 gallons per head; and where manufacturers' refuse has to be contended with, the dimensions of the sewers must be proportioned to the quantity issuing, or else a separate sewer must be built to take this refuse on to land for isolated treatment. Text-books will recommend the student to provide for 25 to 30 gallons—equal to twice the quantity used in an ordinary dwelling-house. No doubt the quantity so allowed will provide a small margin for any waters that may be discharged into the sewers from other than dwelling-houses.

The question, however, of the amount of sewage per head of population is, in a sense, of small moment compared with the difficulty of the prevention of floods in our towns from heavy rain storms.

Rainfall.—In a report published recently in one of our technical journals of a sewerage scheme which had been carried out, it was observed that the sewers were so designed that ½ inch of rainfall per day, together with the flow of sewage, would be carried off, the rainfall being obtained from statistics (no doubt from a trustworthy source, such as Symons' *British Rainfall*) of the average fall per day in a district close to the one which was under consideration.

It is usual to assume that the number of inches of rain is taken as that falling on the built-up area, and for my purpose it is so in this case. To design a scheme on such a principle appears to me to be entirely wrong; and when that scheme has been in operation for a year or two it will not be surprising to hear that the capacity is not sufficient for the requirements of the town.

For waterworks' purposes, the average amount of rain which falls during a day or during a year will give the engineer an idea of the quantity of water to be obtained from the area over which the rain has fallen for storage purposes, allowance having been made for evaporation and absorption; but, if he designed his catchwater to take the water to the reservoir at this rate, he would soon find what a vast mistake had been made. It is so in sewerage schemes, the average rate of fall per day is by no means the basis to adopt; the rate must be the mean of a series of averages over a period of, say, ten years, or a reasonable maximum at which the rain actually falls. Rain gauges are usually attended to once in twenty-four hours, and most of them have no automatic arrangement registering the fall. For sewerage schemes the non-automatic rain gauge is of no value whatever. A striking example of their uselessness in this respect was brought prominently before the writer quite recently, and on three different occasions. A very heavy rainstorm fell on the first day, which lasted barely half an hour. On making inquiries next morning, the rain gauge registered 1¼ inches during the previous twenty-four hours—a rate of fall fully provided for in the design of the sewers which had to deal with the storm. As a matter of fact, the rainfall was at the rate of nearly 3 inches per hour—0·96 inch in twenty minutes was recorded in the local newspapers—or 72 inches per day. The same, or nearly so, was the experience of the other two occasions. As the sewers had not been designed to deal with such a vast quantity of water, they naturally overflowed into the cellars of factories, into workshops, and on to the streets. The owners of the factories are instituting an action against the Corporation for damages. It would be an unreasonable thing to suggest that sewers should be designed to contend successfully with such an enormous downfall; and, if there should be an automatic rain gauge registering the rain as it falls to prove the abnormal character of the fall, a court of law would support a corporation or local authority with greater confidence than is possible under existing conditions. It should, not only on this account, but for purposes of inestimable value in other respects, be imperative in every town that an automatic rain gauge be placed in a suitable position. It is, comparatively, such an inexpensive apparatus that it is surprising that it is not adopted more frequently.

An engineer with a record of a number of years' hourly rate of rainfall would be able to obtain a fairly accurate idea of what capacity his sewers should be designed to take.

Having obtained the average or maximum rate of fall per hour, we have only proceeded half-way into the inquiries; there is the question of velocity of entry of the rain into the sewers. It has been stated that in a rainfall lasting half an hour only 50 per cent. of the water enters the sewer during that time; on what authority, or whether it was mere guesswork, I am not able to say. From a superficial view, I should say that for a lingering rainfall this percentage would be too large, whereas in a short, sharp, heavy downpour this estimate might be very near to what actually might occur. If such be the case, then a rainfall at the rate of 6 inches per day would flow to the sewer at the rate of 3 inches.

The above inquiries having been satisfactorily settled, we should easily be able to fix the sizes of our sewers. They have been very unsatisfactorily answered in the past, as will be seen from the following figures, which have been taken from the main drainage report to the London County Council:—

Bradford	provides for	4	inches	per 24 hours.	
Bristol	,,	1	,,	,,	
Hanley	,,	2 to 3	,,	,,	
Leicester	,,	2	,,	,,	
Liverpool	,,	4	,,	,,	at one outfall.
,,	,,	12	,,	,,	at another outfall.
Manchester	,,	½	,,	,,	found to be inadequate.
Nottingham	,,	1	,,	,,	
Sheffield	,,	0·41	,,	,,	at new outfall.
West Bromwich	,,	1½	,,	,,	

Presumably these figures refer to the fall on the built-on area. In a paper read at the Institution of Civil Engineers, the collecting sewers of the Buenos Ayres drainage scheme were stated to be of a capacity to take 1½ inches per hour or 36 inches per day. Surely these statements must awaken the minds of engineers to the apparent want of uniformity. Is it that there are abnormal rains in one town not to be found in others, or is it that in some towns the rain enters the sewers immediately it falls? One finds it a difficult matter to understand the statement that at Liverpool one outfall is constructed to take only 4 inches, and at another it is found necessary to have one discharging 12 inches per day. The new outfall sewer at Sheffield is designed to take only 0·41 inch, whereas at Manchester ½-inch fall is found to be inadequate. At Leicester the rainfall provided for is given as only 2 inches. I think, as a matter of fact, the collecting sewers have a capacity of 6 inches per day, the storm overflows in the town taking 4 inches, and the main storm overflow discharging about four miles out of the town the 2 inches referred to above. The cry of ratepayers is for economy. Why spend their money in an extravagant or loose manner by constructing large sewers if small ones will answer the purposes? or, on the other hand, why provide small sewers where large ones are required?

The method for fixing the minimum capacity of a sewer up to its outfall may be based on the following lines of argument:—Firstly, the sewage at its existing outfall should be analysed as to what is the maximum amount of "albuminoid ammonia" or "oxygen absorbed"; secondly, the dry weather flow of the river or watercourse into which the purified effluent or storm water is to be turned should be obtained, together with an analysis of the "albuminoid ammonia" and "oxygen absorbed." It would also be a useful point to know the self-purification action of the river water. Having obtained these, we may proceed somewhat on the lines of the following example:—Crude sewage is of a different composition in every town. The maximum amount of albuminoid ammonia will be 1·5 grains per gallon in one town, and in another as low as 0·4. For our purpose I shall take 1·5 grains per gallon as the quantity. If this sewage were so diluted with water that only contained 0·04 grain per gallon, it would be in a state sufficiently pure to be allowed to enter a river or watercourse after the solid matter had been eliminated. An average house contains five persons, its area is 340 square yards; cottage houses with half the front and back streets take up a much less area than this, 160 square yards would be nearer the mark. Taking 18 gallons per head per day as the rate of sewage discharge per day, there would be a flow at the rate of about 180 gallons per day. To render this pure enough to be allowed to discharge into a river without treatment, there would require to be added 67,500 gallons of water, which equals a rainfall of 4·25 inches per day; but as has been referred to before, the rain enters the sewers at the rate of only half this fall, therefore the rate of fall to be provided for is 8·5 inches.

This should be the standard of purification before the sewage should be allowed to run into an open ditch; the cases, however, are rare where this occurs. It generally happens that a watercourse is near to the site of the proposed or existing sewers, or it is not so far distant that an overflow cannot be easily constructed to connect the sewer with the watercourse.

So that in the general case, we may take it that there is a river, and a fairly large amount of water flowing. In a river not contaminated by sewage effluents the quantity of albuminoid ammonia is less than 0·04 grain; in our case we shall allow the river to contain 0·01 grain per gallon. In consequence, we may turn the sewage into the river at less diluted proportion than 1 to 37·5. If the quantity of water in the river is more than that intended to flow through the storm overflow, the dilution may be very considerably lessened.

In the case of the River Calder, in Yorkshire, the drainage area is approximately 231,500 acres, and the population in this area is 654,000. The dry weather flow is 84,000,000 gallons per day. Divide this quantity by 50, and we have 1,680,000 gallons; that is to say, that at the convergence of the Aire and the Calder we might pour in 1,680,000 gallons of sewage containing 1·50 grains per gallon of albuminoid ammonia, and the effect generally on the river water, assuming it to be contaminated with 0·01 grain per gallon of albuminoid ammonia, would be sanctioned by the Local Government Board, provided that the solid matter was taken out. But the sewage from 654,000 persons would at 18 gallons per head be 11,772,000 gallons, and this would have to be diluted 31·00 times its bulk before it could be allowed to enter the river, so as to obtain in the latter a dilution of 1 to 37·5, or that the river should only contain 0·04 grain per gallon of albuminoid ammonia. Thirty-one times the bulk of this sewage would mean a rainfall on the built-up area of 1·60 inches per day, but as the flow of sewage is at the rate of twice the total flow per day, this rainfall would have to be doubled—*i.e.*, to 3·20 inches per day. Again, the rain enters the sewer at only one-half of the velocity it falls, and the rainfall would therefore have to be at the rate of 6·40 inches per day, and this would be the rate of flow required in the sewer before it could be allowed to enter the river under circumstances parallel to that described. The above is rather an extreme example, so far as the number of grains per gallon of albuminoid is concerned. The mean average of the sewage of a manufacturing town in Yorkshire, as shown by a recent analysis, was 0·64 grain per gallon, and a mixture of trade effluents from dye works, chemical works, soap works, spinning and cloth mills was made, and the analysis gave 1·34 grains per gallon.

The same, or a very similar result would be obtained if the amount of "oxygen absorbed" instead of "albuminoid ammonia" had been taken as a basis. There are other points well worth the attention of engineers, matters which have received much thought in the past; but probably on account of their having been in the hands of engineers to local authorities, who have, as a rule, their hands full with other works, and have not consequently been able to devote their minds to these favourite problems, have had to allow them to lapse. They can only be subjects for theorising until one can find a situation where the theory can be demonstrated in a practical manner.

The Separate System.—The separate system has been the pet theory of many engineers, and I have little doubt but that the restrictions of the Local Government Board and the Rivers Boards will eventually cause this system to be adopted, not by compulsion on their part, but by force of circumstances.

The separate system would be carried out in a town with good gradients; it is policy to do so, and if this is the case, which we may admit for the moment, then it is also policy to do so in all other cases.

By this system the treatment of sewage at the disposal works is reduced to almost a minimum. One week's sewage would be the same as that of the next, and the method of treatment once settled satisfactorily would not vary. An objection—and a serious one, especially for small towns—is that sewers have to be large in comparison with the quantity of water flowing. The flow of sewage in a sewer varies with every hour in the day, is least at midnight, and increases to a maximum at about 10 to 11 o'clock a.m. and 3 to 4 o'clock p.m. Generally speaking, the flow at the maximum is about eight to ten times greater than at the minimum, and, unless the dimensions of the pipes or sewers are so arranged that the wetted perimeter is proportioned to the flow of sewage, the velocity will also vary; if circular pipes are used this does occur to a very large degree. Sewage itself is of a variable specific gravity, and until experiments have been made in sewers having side junctions into them, which must affect the velocity either by decreasing or increasing it, we shall not be able to fix any velocity, which may be called a self-cleansing velocity—*e.g.*, a sewer has a fall of 1 in 100, that sewer, according to a formula, will give a velocity, say, 3 feet per second when running half full. A sewer, however, has a place where there is no water running into it—viz., at the summit. Suppose that at the summit a side junction admitted sewage which would half fill the sewer, and that it enters with no initial velocity, then the sewage must travel some distance before it attains the velocity of 3 feet per second; as a matter of fact, the sewage would enter with a considerable velocity, which would consequently reduce the distance. The effects of side junctions from houses have a powerful action in the change of velocity in a sewer. A more striking example is seen almost as an everyday occurrence. A bowl filled with water which is perfectly quiescent is placed under a tap communicating with a cistern of water; the tap is turned on so that the water flows vertically on to the water in the bowl; this latter then acquires a movement from the right and left towards the point where the water from the tap enters, and as soon as the tap is turned off the water in the bowl becomes quiescent again immediately. If, on the other hand, a tube be fixed to the tap, and the free end be directed into the bowl at a tangent to the side, and the water is again turned on, the water in the bowl acquires a revolving motion round its centre as axis, which continues when the tap is turned off until the friction of the sides counterbalances the movement.

Side junctions should therefore be directed into a sewer at the least angle possible. A velocity should be fixed for the minimum flow, so that when the maximum flow is running the sewer should be self-cleansing.

In many towns there is a very large quantity of pure water turned into the sewers simply because there are no surface water drains or any watercourse near at hand to receive it. There is the spring water above mentioned; there is also the condensing water from engines, the washing water from the cleaning of pans, and the refrigerator water from breweries, and no doubt other sources may be found which are not known to me, but are peculiar to the various factories. All this, that is now turned into the sewers, could be with advantage diverted into surface water drains.

A disadvantage of the separate system is that the first washings of a storm are generally accepted to be worse than the sewage in a sewer, and the river into which the surface water flows becomes very much fouled after a heavy rain. It is also pointed out by some that the drainage area for the surface water sewers is very limited. This is, however, merely a question of detail. If the system were thoroughly carried out there would be no such argument.

The conclusions one comes to from the above considerations are that at the summit of every sewer the sewers should be on the combined system, until the velocity shall be such that it will keep them clean without any attention. As there may be some misunderstanding as to my meaning, I will endeavour to elaborate it in as brief a fashion as possible. It may be said that at every dwelling is a summit of a drain, and therefore the whole system would be "combined." But every house in a well-regulated town has its sewers falling into the main drain at a minimum rate of inclination—viz., 1 in 40 to 1 in 30. This inclination is so great that it is rare indeed to have a complaint as to their being stopped up. But these house drains run into a sewer having a much flatter gradient—say, at 1 in 240. Each house has an area of 340 square yards; a 9-inch pipe running half full will discharge at the rate of 3 feet per second 40 gallons per minute. One house, however, will discharge on the average only 90 gallons per day, or at the maximum rate of 180 gallons per day, or only ⅛ gallon per minute. A 9-inch drain would therefore, at a fall of 1 in 240, require connections from 320 houses before it had approximately a 3 feet per second velocity. This number of houses represents a drainage area of about 2⅔ acres.

Taking a particular town, and considering the rainfall in the years 1892, 1893, and 1894, it is found that rain fell in:—

AVERAGE TOTAL OF THREE YEARS.

1892.	1893.	1894.		Inches.
14 days,	10 days,	18 days in	January,	1·36
10 ,,	15 ,,	13 ,,	February,	2·56
7 ,,	5 ,,	8 ,,	March,	0·76
9 ,,	4 ,,	17 ,,	April,	1·63
13 ,,	7 ,,	13 ,,	May,	1·83
17 ,,	11 ,,	10 ,,	June,	2·90
9 ,,	16 ,,	9 ,,	July,	2·63
13 ,,	14 ,,	14 ,,	August,	2·09
14 ,,	8 ,,	5 ,,	September,	0·91
17 ,,	12 ,,	18 ,,	October,	3·70
12 ,,	16 ,,	10 ,,	November,	1·11
6 ,,	13 ,,	12 ,,	December,	1·38

From the above figures it may be taken that rain will fall at least once in four days throughout the year. If it were possible to obtain the rate of fall during the rainy days, we would then have a fair though an approximate basis which would enable us to say whether the sewers were able to be kept clean without the use of flushing tanks, and, in consequence, reduce this 2⅔ acres to a minimum.

It has previously been suggested that the sewers at their summits should be designed on the combined system, and that below this the sewage and surface water should be separated, the surface water being taken from every possible area. The first washings of a storm are, as has been mentioned, detrimental to the carrying out of the system. The first washings from roofs of houses, footpaths, and backyards are not appreciably deleterious; the fouling occurs from the washings of the roadways of our streets and roads. The separate system should only be for the drainage from the roofs and the backs of houses, which is generally in contradistinction to the manner the separate system has been laid out in the past. The water from the roadways must therefore be dealt with by either of two methods—*i.e.*, it must go directly to the sewers, or be dealt with on the separate system by employing a device to prevent the first washings from entering the rivers. This may be done by constructing underground tanks of a capacity of one hour's flow at the rate of $\frac{1}{12}$ inch of rainfall per hour. As soon as the tank becomes full, a weir placed at the end farthest from the inlet—which should be at the bottom of the tank—would allow the water to pass on to the river. The tank would be in the form of a filter and precipitator in much the same manner as the Dortmund tanks. The water in the tanks after the rain had ceased might be syphoned off into the sewers at the convenience of the engineer or those in charge of the sewerage system.

CHAPTER XV.

SEWAGE DISPOSAL.

249. The disposal of the sewage has been touched upon in one case, that in which the sewage is sent out to sea, but it is necessary to consider the cases where it is intended to purify it on land.

There are many methods of treatment, but they may be reduced to four classes—(1) Broad irrigation; (2) intermittent downward filtration; (3) chemical precipitation, combined with land filtration or specially constructed filters; and (4) bacterial treatment.

1. **Broad Irrigation.**—The system of broad irrigation has been evolved naturally. In the most primitive case the sewage from a few houses was allowed to run, deposit, and drain through an adjoining field, and as the sewage continued so to flow without being an apparent nuisance, it was seen that, especially if it happened to be evenly distributed, the vegetable growth appeared to be all the better for it.

The process inaugurated in this manner has been developed, and has been called broad irrigation.

The Local Government Board require, should this system be adopted, that land shall be provided in the proportion of one acre to every hundred of the population that is to discharge sewage on to the land.

250. Where a scheme of broad irrigation is adopted, it is not necessary to provide depositing tanks, although they are often included in order to remove by screening and subsidence a large amount of the solid matter in the sewage; the flocculent matter is also retained in the tanks to a considerable degree. They are useful in regulating the distribution of the water, and also for the collecting and storing the night flow of sewage, which may be dispersed on to the allotted areas in the morning when the watermen are at liberty to attend to it.

For the system of broad irrigation the land should be of very suitable character, or it will require considerable expense and care to prevent failure from the sewage purification point of view. If the liquid is allowed to run without systematic attention and a full knowledge of the capabilities of the land it will give but very poor results. A sewage farm should first be for the purification of the sewage, the minor position being the raising of crops.

A loose loamy soil for a depth of 5 or 6 feet will give excellent results, provided the land is given periodical rests. If there should be a layer of clay some 3 feet below the surface it could be made to work satisfactorily by a proper system of drainage. Drainage would be required in the land with a deep bed of soil, but not in anything like the same proportion.

Clays differ considerably in their composition; some are very sandy, and would be to a slight extent porous; then there is what is termed a "clay," but is really consolidated alluvial deposit—*e.g.*, mud, which when water touches it turns to a kind of quicksand. Another kind is stiff and perfectly impervious.

In this system the water is supposed not to penetrate deeply into the ground, but to pass over the surface of the soil in thin layers, in order that it may take up oxygen from the atmosphere, and also that the plant life may change the ammonia compounds into nitrates; the latter form of chemical change takes place in the dark, and therefore must be below the surface.

251. The natural drainage of the subsoil may possibly be sufficient for the removal of the water which penetrates into the soil; if it proves to be too heavy, a system of land drainage must be laid down in order to assist the water to pass away to a stream.

The water must not pass too quickly into these drains, as the land and vegetation must have sufficient time to allow of the conversion and assimilation of the organic matter by the plant life; the drains must therefore be collected and pass through an inspection chamber; these may be provided in a corner of the field, as shown in Fig. 130 at the point A. Should the effluent which passes through this chamber not be satisfactory, it may be turned into a drain continued from this inspection chamber to the nearest point that will allow it to discharge on the surface again. Similarly, if the water that travels over the surface of the soil when it reaches the lower end of the field is not satisfactorily purified by surface filtration and oxidation, it is turned on to the next lower field. The fields nearest the watercourse, where this secondary treatment cannot be managed, are generally reserved for the night flow of sewage, which is usually very much weaker and more easily purified than that discharged during the daytime.

The efficiency of the land drains must be tried by experimenting, as some soils require the drains to be much closer together than others.

252. With sewage that is strongly impregnated with deposit and excreta, the area of one acre to every hundred of the population is not sufficient for its satisfactory purification. The author found that the best results were obtained by dividing the total area
three parts, and giving one area a complete rest of one year,
area intermittent rest and only a small quantity of
remaining third being used up to its full capabilities.
tter portion such plants as Italian ryegrass, mangold

wurzels, and cabbages could be grown. On a certain portion which was very light and loamy were planted osiers and willows, which grow abundantly in a swampy soil; on the second portion lighter crops were grown; and on the third area, which had an intermittent rest during one year and a complete rest during the

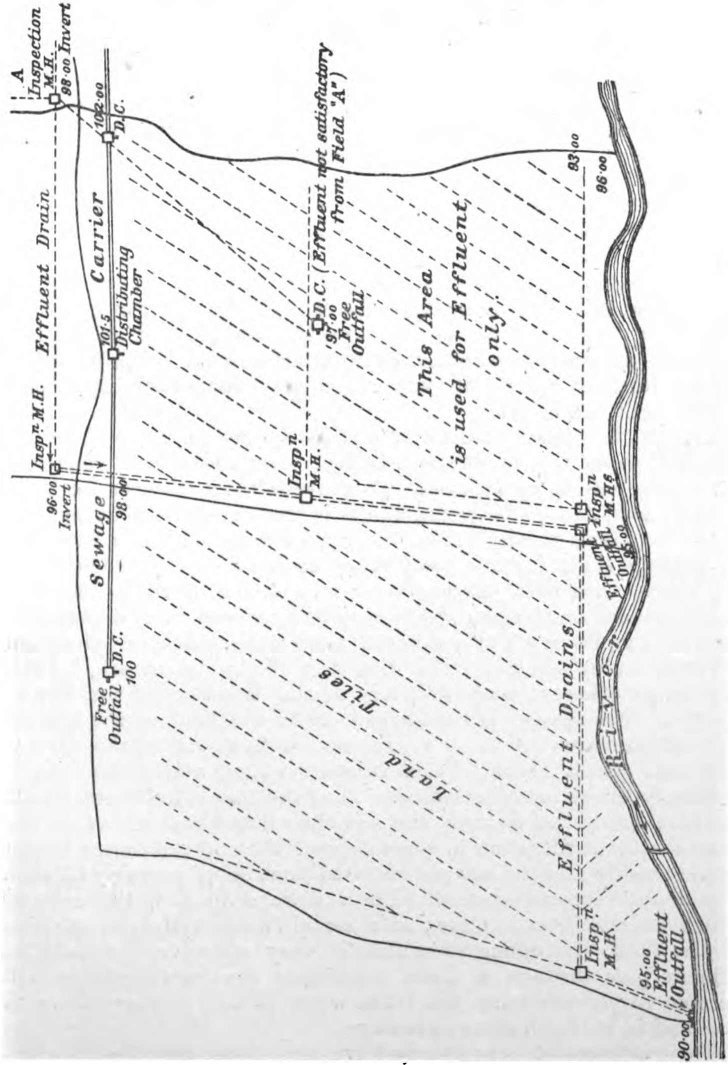


Fig. 130.—Sewering an irrigation area.

second year, there was planted in the last year crops of wheat, oats, or barley. On some farms the sewage is run over pasture-land, and the grass is kept short by beasts, which seem to thrive on it. At Leicester the cattle brought in very fair prices.

At West Derby and Walton the caretakers have been awarded prizes for the specimens of green stuffs, these farms being the first to send ryegrass into the Liverpool markets.

253. Great care should be exercised on sewage farms that the sewage be distributed evenly and at certain fixed periods depending on the nature of the soil. Sewage must not be sent in large quantities on to the land without regulation; it would rot the vegetables and cause interminable mischief in the subsoil. Weeds should be systematically removed and kept vigorously down, as their seeds, when distributed by the sewage and not attended to, will grow so abundantly as to overpower the cultivated plants. The land should be closely watched in order that the quantity it will deal with, with some degree of safety, may be gauged approximately. The quantity varies with the quality of the soil; almost any soil can be made to purify sewage, and about 200 inches in the year may be poured on to an acre (= 2·6 gallons per square yard) of some soils without in any way swamping it and rendering it ineffective.

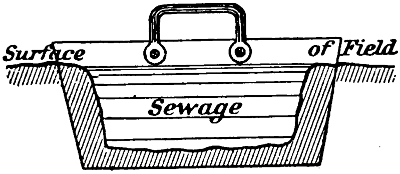
254. If the subsoil consists of a stiff clay the surface will, in hot weather, when the moisture has been evaporated and removed, show large cracks or fissures. To prevent these fissures forming, the soil must always be moist, and it is therefore desirable that the water be taken to the drains at a slow rate, which is obtained by placing them further away from each other. In some cases the surface has been covered over to a depth of 15 inches with clean cinders and ashes, which may be obtained from destructors or from ashpits in a water-closeted town; the ashes are ploughed into the clayey top soil. The direction of the drains are, in this case as in others, placed obliquely to the direction of the flow of sewage. The sewage is discharged on to the field at the highest part of the area of land so raised; it flows on to the surface and also passes through this raised portion, and laterally and gradually filters into the drains. Thus the clay is kept moist, and, as there can be no fissures, the sewage cannot pass direct to the drains without filtration in some degree. Should the drains be put in too thickly and the sewage enter without being properly filtered, the drains become choked with a sewage fungus, the cells of which contain free sulphur; at a certain stage hydrogen sulphide is given off, the odour of which is very offensive. Should an effluent pass through a drain containing sewage fungus, it will become very much more foul than when it was discharged on to the land in its fresh state as sewage.

The surface of the land may have any slope, but the distribution of the sewage is less costly if the slope be small, such as 1 in 80.

255. The sewage is carried to the areas by means of conduits, which are constructed of brickwork or concrete, or formed in the earth, and pass from the outfall of the sewer to the summit of the land proposed to be treated. The dimensions of these conduits must be such that they will take the full discharge of the sewer to any section of the farm that may have been allotted to deal with that quantity. The carriers should be given only a slight gradient, and where the invert would run out from the surface they should have vertical drops in order that the sewage should fall and be, to a certain extent, aerated by such a fall.

256. From the main carrier there are outlet junctions which will distribute the sewage on to different areas or plots. If the plots are some distance away from the main carrier, branch carriers are constructed. The outlets discharging direct on the lands are usually placed above the flow in the main carrier, the sewage being dammed back by wooden weir sluices across the carrier until it finds its way through and on to the land.

These outlets discharge the sewage into what are termed "main grips"; if the field is a large one, it is subdivided and small carriers run to each of the subdivided portions, the carriers having free outlets into grips. These grips are in width equal to an ordinary farmer's spade and about 6 inches in depth; it runs along the summit of the area to be treated. An iron plate of the form shown in Fig. 131 is placed at about every fifty yards; they are a little wider and deeper than the grip itself, and form a stop to the flow of the water in the direction of the grip; the water therefore, flows over the surface in thin layers, a proportion of the matter is assimilated by the plants, another part by filtration finds its way into the subsoil drains, the remainder passes by lateral filtration through the grass or particles of the soil over the surface of the land, and is intercepted at the foot of the area by an effluent grip; this may be passed on to another lower area, if it should be deemed necessary to be further purified. If it is sufficiently purified, it may be allowed to run direct into an effluent culvert or into a ditch, either of which may communicate with a river or stream.



GRIP - WITH STOP-PLATE

Fig. 131.

257. The subsoil drains should be so laid out that certain areas may be drained into inspection chambers. It is here that the quality of the water that filters through the land is examined. If

it should prove to be good, the sewage may be run direct into the drains without further filtration. By confining the area to about one or two acres for each inspection chamber, the effluents from different chambers may be compared, and, should they not be equally satisfactory, the cause may be the more easily located if the areas are small.

258. The subsoil drains are usually about 3 to 4 inches in diameter, of the usual agricultural type of tiles. The smaller discharge into larger drains ranging from 6 inches diameter upwards. The latter are not open, and do not act as drains after they pass the inspection chambers. The land tiles are butt-jointed, and are covered with small pieces of stone, brick, sods, &c., or any material that will allow water to have access, but not so open as will permit the drains to be choked with soil percolation or with the soil when filling the trench after the pipes have been laid. They are generally laid diagonally to the direction which the sewage takes over the surface; this is in order to prevent, as much as possible, the sewage running through the trenches direct to the drains before it passes properly over the land. The tile drains are laid about a chain apart, but nearer when so required by experiments.

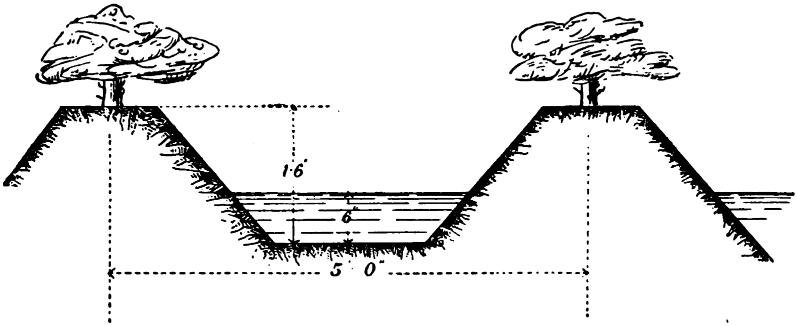


Fig. 132.—Intermittent downward filtration.

259. Great care should be taken to find out where the existing land drains are situated. These would probably be too near the surface for the effectual treatment of the sewage, and would have to be pulled out. They show themselves when the sewage is poured on to the land by fouling the streams, watercourses, or ditches into which they may discharge.

For small sewage farms the carriers are not constructed of earthenware or brickwork, but a channel is dug out of the earth in the direction required; a half-pipe is occasionally laid down as an invert in order to obtain a better flow of the sewage.

260.—2. **Intermittent Downward Filtration** is a system which has been very successful in purifying sewage. The process originated in a laboratory. The system has been adopted in many towns with great success, Mr Bailey Denton, M.I.C.E., being the engineer who has brought it into prominence. It requires that the soil shall be loose and sandy to a depth of 6 feet, in which condition one acre will efficiently purify the sewage of 1000 persons. If the soil vary in character, the efficiency per acre will also vary. The land is laid in level plots or terraces, and divided by ridges and deep furrows, the ridges being about 5 feet apart and the furrows about 18 inches deep (Fig. 132). The ends are blocked, and sewage is allowed to enter this temporary earth tank to a depth of 6 inches, so that the water will barely touch the roots of the plants growing on the ridges. When filled, the flow is stopped, and the water begins to filter through the subsoil to the drains. After the water has disappeared from the surface several hours are allowed to elapse before any more sewage is discharged into the furrows. This rest enables the subsoil to regain its filtrative powers by aeration. The ridges and furrows should constantly change places, in order that the sewage deposit on the sides of the furrow may be assimilated or decomposed by the organisms. The subsoil drainage is similar to that already described in the section on broad irrigation. The solid matter should, if possible, be removed by screening or subsidence before it is allowed to enter into the furrows, or it should pass through rough stone filters. Should this system be carefully attended to, the efficiency and purification will be easily maintained.

261. The tanks (already mentioned), which are for the purpose of removing the solid matter and rendering the sewage in a better state for land treatment, are built in three types—the "continuous," the "semi-continuous," and the "resting."

The *continuous* type of tank is that which permits the sewage to enter at one end above the surface of the sewage with which the tank may be filled, and which continuously moves without a rest until it discharges at the other end of the tanks, the level of the channel discharging the tank effluent differing only by a few inches from the level of the entering channel. The water flows from the sewer along a channel until it enters the tank, which it does by passing over a weir very greatly wider than the channel; thus the velocity of the water is decreased. The depth of sewage on the weir compared with that in the channel is, of course, proportionately lessened; it flows into the tank, as a general rule, in a very thin layer; it is decreased still further by having to pass through the tank by displacement, the velocity through the tank being about 1½ feet per minute, and to allow the fine solid matter to deposit, it should not be greater than at the rate of 3 feet per minute.

The recent designs of tanks have an important modification. The sewage, instead of passing over a weir, is made to run from the channel down a slope and through holes in the bottom of the wall, the latter wall taking the position of the weir, as shown in Fig. 133. Here the sewage must go to the bottom of the tank before it reaches the surface again. The solids, in subsiding from the top water in the tank where the water is practically quiescent, bring with them those which are newly entering the tank; thus, so to speak, the depositing material, in the process of subsiding, is acting as a filter to the incoming sewage, and thereby increasing the subsiding powers of the tank.

262. The flow of the sewage may be measured by instruments. One instrument is of such a nature that it may be dropped to any position in the depth of the water, and the velocity measured by taking the time that a small projection attached to the vessel—which shows on the surface—passes two fixed points. This instrument is sometimes used in obtaining the velocity and direction of currents in sea water. Another simpler, but approximate, method may be adopted to determine the velocity, viz., by placing in the water an article of the same specific gravity as the liquid—*e.g.*, an orange, turnip, or a bottle nearly filled with the liquid so that the cork only is exposed, and measure the time it takes to traverse a certain fixed distance.

The theoretical velocity is measured as shown in Art. 318.

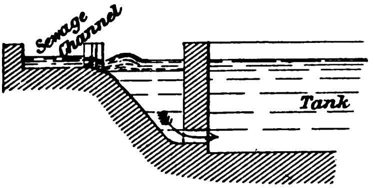


Fig. 133.—Entrance to depositing tank.

263. The capacity of the tanks is divided into such units as may be suitable for the quality of the sewage to be operated upon—*e.g.*, a sewage may be of such a character that very little, if any, need pass through the tanks; or that if it pass through at the rate of 3 feet per minute, it is quite sufficient for the subsidence required. On the other hand, it may be found necessary to have a slower flow than 1½ feet per minute. Arrangements should therefore be made that it may either rest completely or pass through another tank.

The capacity of the tanks which are designed for the continuous or semi-continuous flow need not be so large as those where the sewage is allowed to rest 12 or 24 hours, and then decanted by means of floating syphons. The tanks on the resting principle are now being abolished, as the different percentage of deposited solids obtained in the continuous tanks and the resting is not proportionate to the expenses of the extra tanks required in the latter. The dimensions of the tanks for all sizes depend on the rate of flow of the sewage in the tank.

264. The sludge from the bottom of the tanks is obtained by decanting the top water through a floating valve into an effluent

channel delivering on to the land. The sludge is then swept by manual labour to openings which communicate by a pipe or channel with the sludge pit, where it is allowed to stand. After the top water has been removed into the sewage well, it is pumped up, and either pressed by sludge presses or removed on to land set apart for the purpose.

265. There are now arrangements by which the sludge may be removed without decanting the top water.

The principle is that of a syphon; it is very simple and effective.

In Fig. 134, B C E F represents an iron tube, B C being parallel to the bottom of the tank J K L M, and about 2 inches above it. A and B are the carriage wheels connected with the tube, which run on tram lines throughout the whole length of the tank. On the under side of that portion marked B C, holes are cut, through which the sludge is permitted to enter the tube.

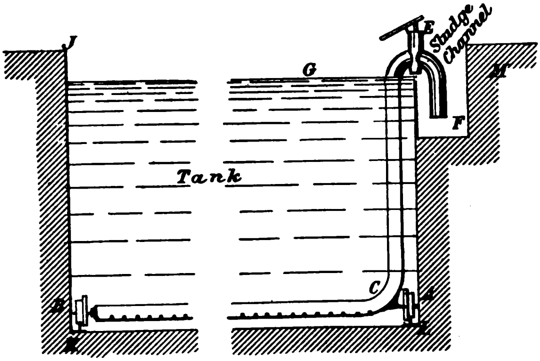


Fig. 134.—Tank.

Attached to the length B C immediately above the holes, and sweeping the full width A B, is a piece of india-rubber just touching the concrete floor. A pump is placed in the position E, which is used to fill that part of the tube marked E F with water from the tank; when water issues from the outlet the action of the syphon is commenced, and liquid will flow through the end of the tube F until the surfaces G and that in the sludge channel are level. This liquid must be sludge from and about the floor, as the only openings in the tube are at the bottom of the tank. The apparatus is drawn along the rails by means of a chain fastened to winches, which are worked at either end of the walls of the tank. The india-rubber scraper ensures the bottom being properly cleansed.

266. There are other modifications of the same principle. A floating pontoon may be used instead of the channel, and the tube, instead of being exposed, may be connected with the side or under surface of the pontoon. Flexible tubes may be used for conveying

the sludge to fixed points below the surface of the water along the sides of the tank.

The use of these tubes for removing sludge increases the capacity of the tanks; they do not have to be emptied and cleaned, thus giving an extra tank for subsidence purposes which would otherwise be standing.

The sludge would be removed from these tanks every three or four days, otherwise it attains such a density that it cannot efficiently be removed; the liquid in the tank is also detrimentally affected by too great a quantity of sludge in the tanks.

267. There are many varieties of tanks, the object of all being to increase the efficiency of the subsidence, and to decrease the number of tanks, and consequently their total capacity.

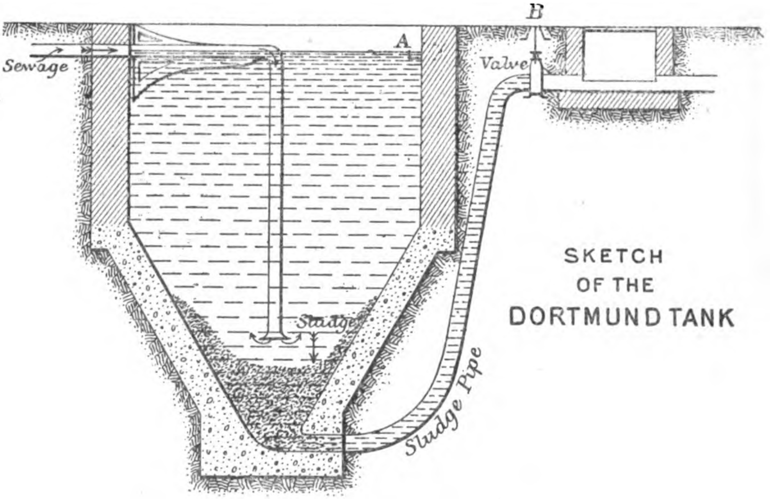


Fig. 135.—Dortmund tank.

They are mostly modifications of the tanks that were put down at Dortmund in Germany, and are known as the Dortmund tanks.

The sewage is conveyed by a pipe, as shown in Fig. 135, which enters at the side of a circular tank, with an inverted cone-shaped bottom, and is carried down the centre of the tank to a point about 4 feet from the point of the inverted cone; the outlet of this pipe is bell-mouthed, and the sewage flows upward. The flow being very slow, the solid matter of the sewage subsides and falls to the bottom, and, as has already been suggested, the subsidence of the particles from the top of the tank prevents many of the incoming particles from rising with the sewage; thus the precipitation or subsidence of the sewage is greatly accelerated by this form of tank, which is about 20 feet in depth. The depth of the old form of tanks rarely exceeded 7 feet. The effluent in this type of tank flows into a channel at A, which runs round the side, and discharges through the wall in the direction required. The sludge is removed by opening the valve at B; the small chamber is for the inspection of the thickness of the sludge which is coming from the foot of the tank; as will be seen, the pressure between the surface at A and the invert of the valve is the force used for obtaining the removal of the sludge.

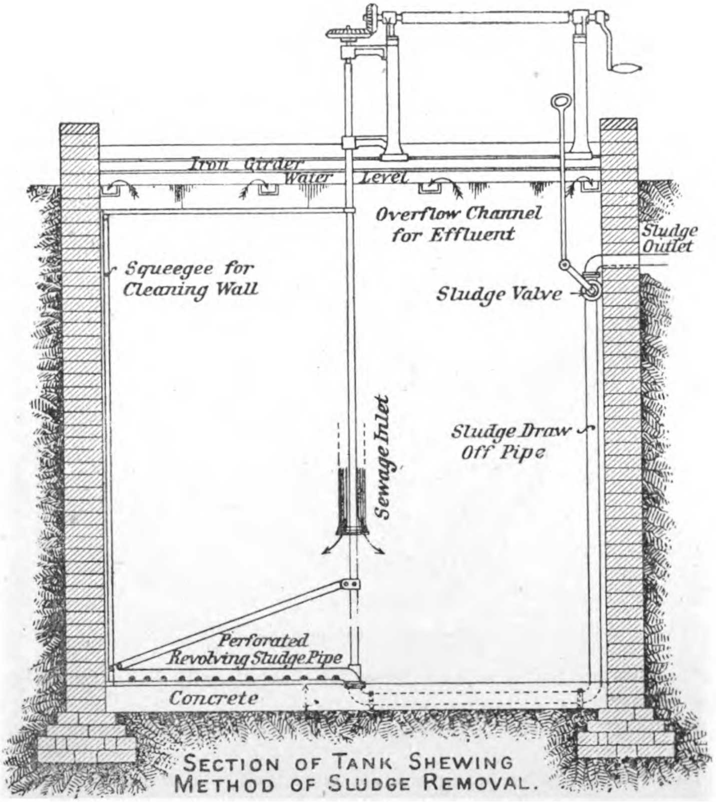


Fig. 136.—Candy's tank.

Occasionally the sides of the cone become so coated with sludge as to be detrimental to the quality of the effluent, but arms have been made which radiate round the sewage inlet pipe, and scrape the sides of the cone; this has been found to be effectual in cleansing the tank of its sludge when in operation with the sludge pipe.

268. The chief advantages of this class of tank are as follows:—The tanks do not cover so large an area of land as would be required for the shallower type; they are cheaper to construct; the sewage has a more equable velocity through the tanks; there is better clarification or subsidence; where chemicals are used a much less quantity per gallon is required; the work of the pumps for sludge purposes is greatly decreased, if not abolished, and consequently less tank capacity is required.

269. Fig. 136 shows a similar form of tank, but in this case the bottom is flat and the sewage sludge is removed by means of the perforated pipe, the action of which has already been described. The illustration explains itself.

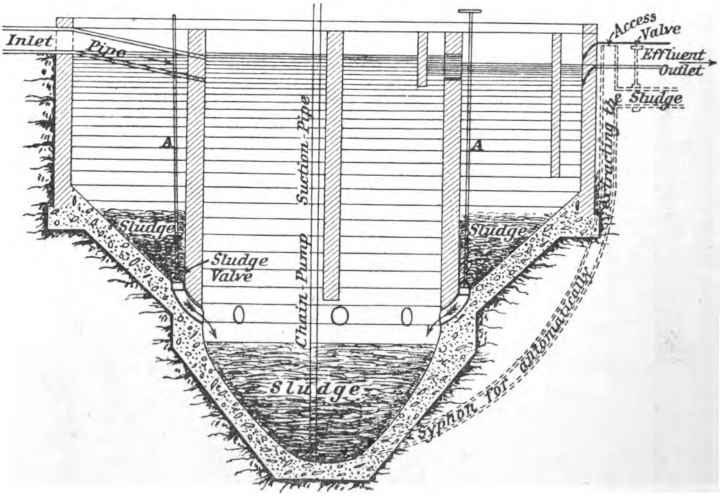


Fig. 137.—Sludge tank.

270. Figs. 137 and 138 show the Natural Purification Company's system.

The sewage, after being treated chemically, enters chamber No. 1, Fig. 138, through the inlet pipe, and then proceeds under the dividing wall into section No. 2; thence through small dividing chamber No. 3, and into No. 4; similarly into Nos. 5, 6, 7, 8, 9, 10, 11, 12, and through box No. 13 into the effluent channel. The velocity through the tank being very slow, the sludge subsides into the positions shown. From the side sections the sludge is allowed to enter the main chamber by lifting the valves A. The sludge is removed in a manner similar to that already described for the other tanks.

271.—3. **Chemical Precipitation.**—There are about 500 different processes which have been brought forward for the purification of sewage; very few of them, however, have ever been heard of.

The sewage of one town is so dissimilar from that of any other that, although a process of chemical treatment may be eminently suited to its purification, it might prove to be quite a failure if applied to any other, and unless the chemical is suited for all kinds of sewage and is cheap both as a manufacture and in application it will rarely be inquired after. In a series of experiments with chemicals and sewage it is quite possible to obtain a beautifully clear and apparently perfect effluent, yet this liquid would, after standing a few days, develop what is termed *secondary decomposition*, which would eventually render the last stage worse than the first. The cost of a chemical might be so great as to be an effectual bar to its adoption, or the mode of its application

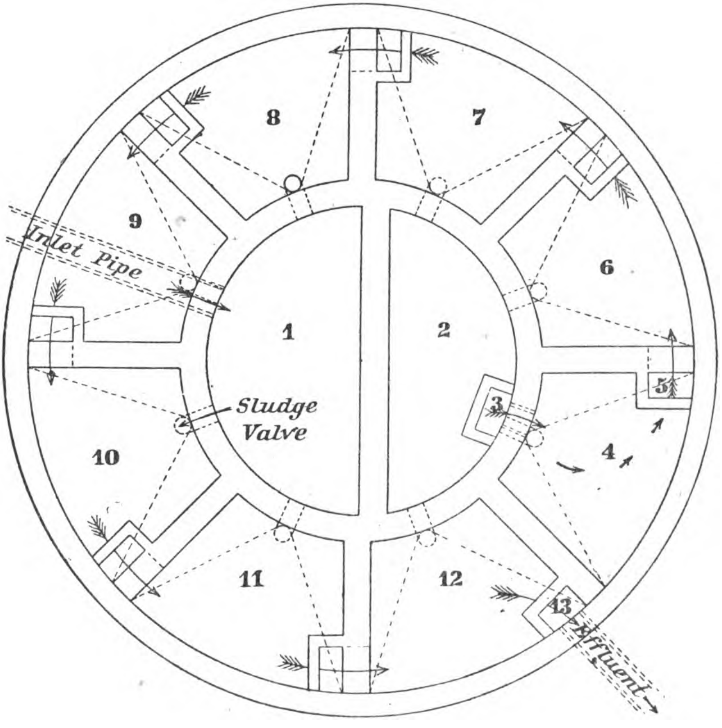


Fig. 138.—Natural Purification Company's system.

might be intricate and entail much labour, which would also prohibit its adoption.

272. In all chemical precipitation processes, the chemical is expected to precipitate the major portion of the mineral and organic matter either in suspension or in solution, and in most cases the precipitate is equal to from 80 to 95 per cent. of the

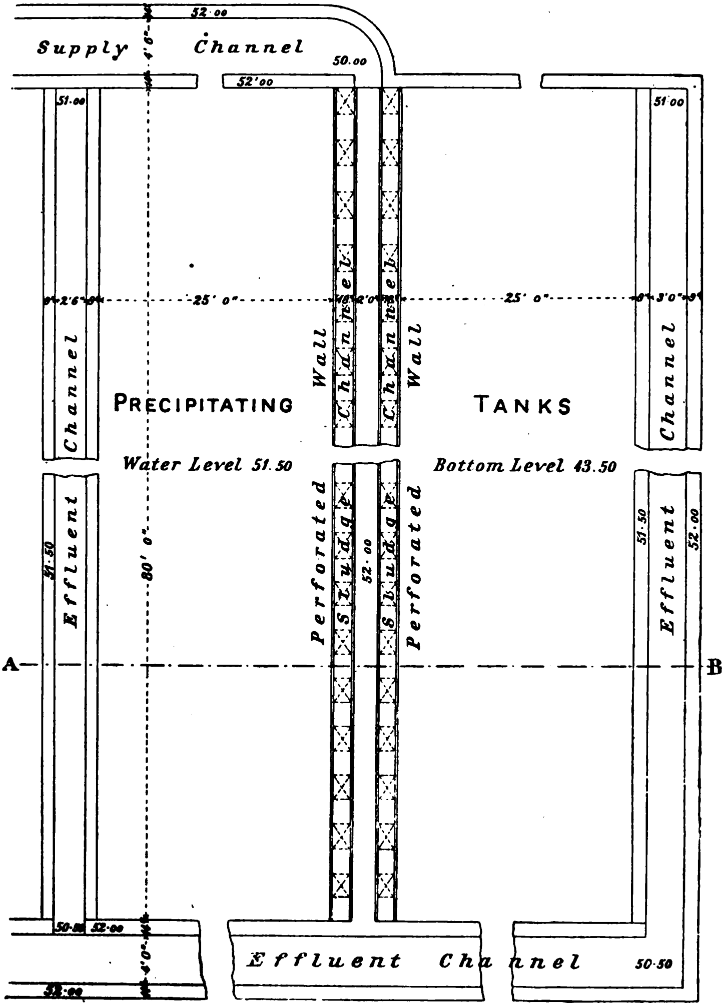


Fig. 141.—Plan of precipitating tanks.

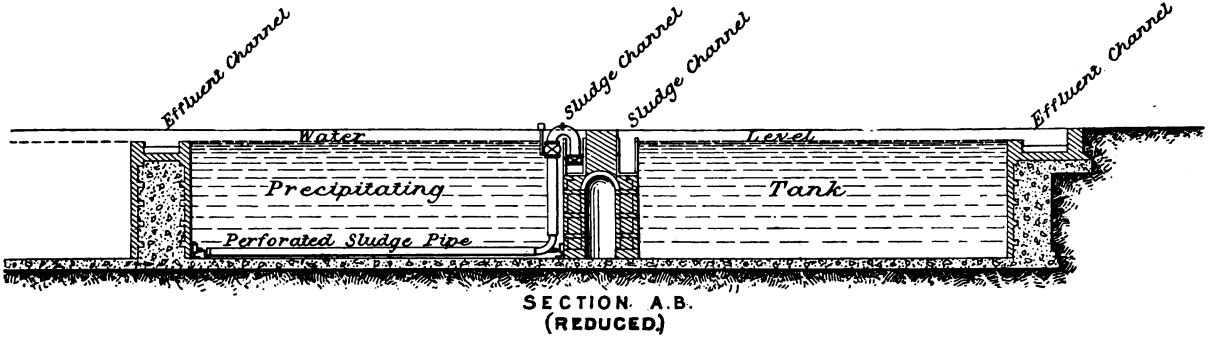


Fig. 143.—Section of precipitating tank.

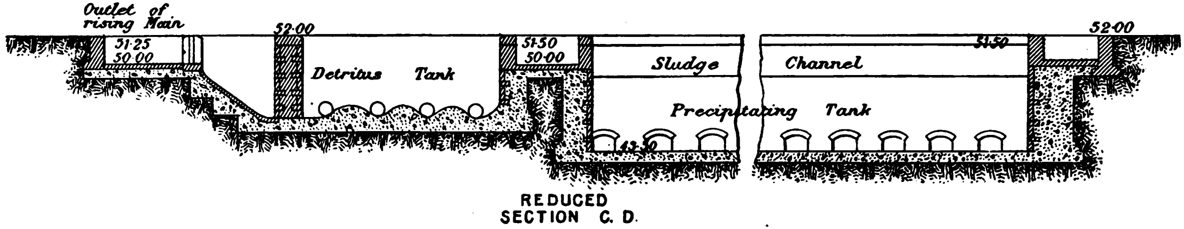


Fig. 144.—Longitudinal section of tank.

solid matter in the sewage. The removal of the solid matter does not, however, necessarily remove the ammonia compounds, and it is found that a certain amount of albuminoid ammonia remains in the liquid, which, if left to itself without further treatment, would develop objectionable compounds, and the water would, in consequence, become very foul. Some chemicals would, by further treatment, reduce the amount of solid matter in the effluent to a minimum, but the expense would be so great in proportion to the gain obtained by passing the effluent over land or through filters that the latter course is adopted. It is, indeed, insisted upon by the Local Government Board, who stipulate that land shall be provided in conjunction with chemical precipitation to an extent of one acre to every 2000 persons.

273. Fig. 139 shows the block plan of a sewage farm laid out on the system of chemical precipitation, with subsequent land filtration. The pumping station is shown near the river, the sewage of the town is discharged into the sewage well, which is shown more in detail in Fig. 142. On this latter plan is shown the buildings which would be necessary for the storing of chemicals, for the sludge-pressing machinery (such as sludge presses, rams, air compressor and receiver, sludge mixer, and chemical mixing machinery), for the pumps, and also for the cells of a refuse destructor, together with boilers for generating the steam requisite for all the classes of machinery. Fig. 140 shows an enlarged plan of the tanks and one of the filtration areas. Figs. 141, 143, and 144 show the construction of the tanks in detail. The sludge is removed from these tanks, while the sewage is precipitating in a manner similar to that already described. The course of the sewage will be easily followed, as the sketches are freely lettered and described.

274. In all schemes it is desirable that the sewage should receive a preliminary screening in order to remove paper, vegetable matter, rags, sticks, gravel, and other solid matter, which would, if allowed to pass with the sewage through precipitating tanks and other processes, be a considerable hindrance and source of annoyance.

There are the ordinary straight wrought-iron screens which are placed below, and inclined to the surface of the flow of the sewage. The refuse collect on the bars, and the latter are periodically raked by hand. There is also a straight-barred screen made by Stott & Co., Haslingden, in connection with which there is a fork arrangement on an endless band, which can be put in operation by either manual or steam power; the forks remove the refuse from the bars and discharge automatically on to a trough or plate, from which it may easily be removed.

275. Fig. 145 shows an endless flexible sewage screen specially made, which runs round the top and bottom drums, D_1 and D_2. The side frames, F, between which the top drum revolves, also carry the clearing and driving gear. On the machine being put in

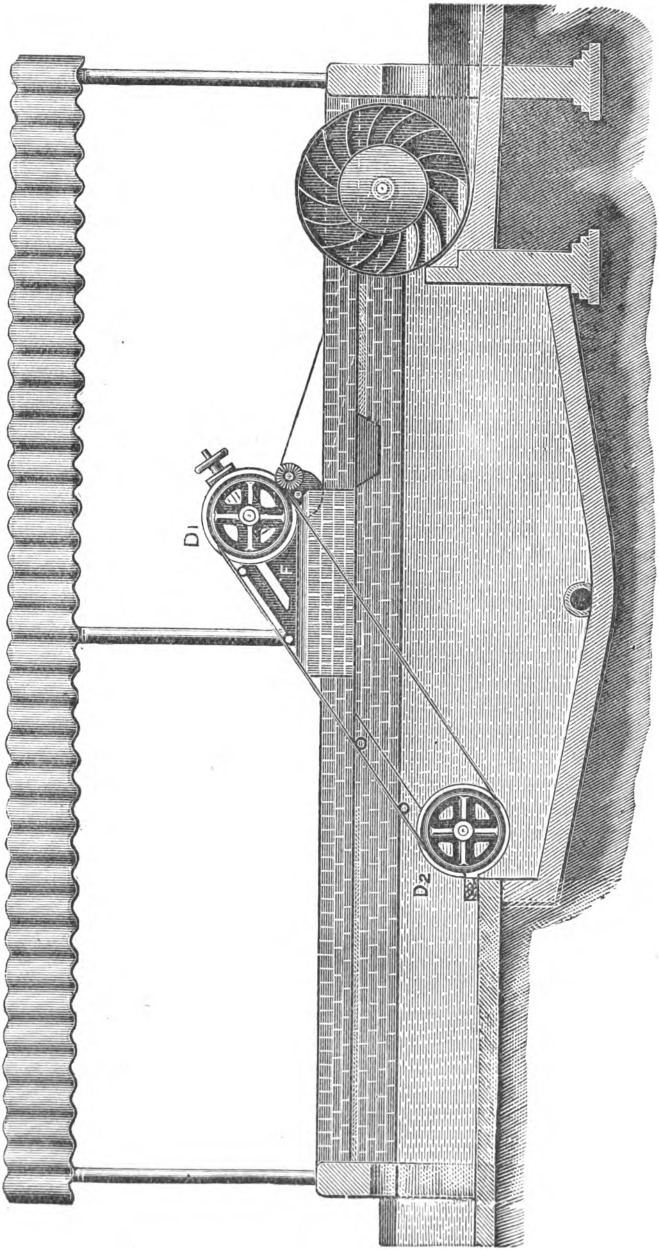


Fig. 145.—Smith's sewage screen.

motion the paper, rags, hair, &c., which would otherwise block and scab a filter bed, are deposited on the travelling band by the sewage as it flows through. The screenings are drawn up and delivered on to the receiving platform for ready removal, either in barrows or by means of a conveyor.

Where a small fall in the main carrier is available (a few inches will generally do) it is desirable to drive the apparatus by the sewage itself. This is done by means of a water wheel, whereby the speed of the band is automatically adjusted to the work it has to do. No special attendant is necessary, which is a matter of considerable importance at night. In other cases any convenient motive power can be used.

276. When chemicals are to be mixed with the sewage it is necessary that they should be thoroughly incorporated with the sewage. There are various modes of adding the chemical. Should it be in the form of a liquid a small lead-lined V-shaped wooden trough is erected across the channel, through which the sewage passes. In the bottom of the trough small holes are pierced, or small V-shaped notches are made in the top edge regularly and equally throughout the full width of the channel. The quantity of liquid is regulated before it enters the trough, which is always full to the bottom edge of the V-shaped notches; immediately the chemical is supplied it drops from the notches on to and mixes with the sewage over its whole surface. In the sewage channel there are bafflers which impede the progress of the water, but are useful in mixing the chemical throughout the entire volume of the sewage. These bafflers take the form of vertical rectangular obstructions jutting out from the sides of the channel, or they may be erected in the centre of the channel. They may also take the form of a paddle wheel, which is turned by the movement of the sewage.

If the chemical is in lumps or solid pieces when in its natural or manufactured state it is usually dissolved to a liquid, in which form it is easier to manipulate and to gauge with comparative accuracy. In this state it is also more readily mixed with the sewage. Machines are to be obtained which grind and reduce large pieces to a powder, and with the addition of water either dissolve the powder or partly do so, as in the case of milk of lime. Fig. 146 shows Kierby's mixer.

There are certain chemical compounds which are manufactured ready for use. The composition is placed in a box or frame, through which the flow of sewage passes. The chemical is easily soluble when in contact with water, and the amount that is dissolved by the sewage in passing is just the quantity required to be added as a precipitant.

277. Short descriptions will be given of the better known processes of chemical treatment, some of which have been in operation for many years; some formerly in use have been abandoned, while

others are prominent on account of their peculiarities, originality, and the discussions and articles which have been written concerning them. There are many that, if they had been tried, would probably have given quite as good (if not better) results than those about to be mentioned; but they have failed for want, perhaps, of an energetic person to bring them before engineers, or on account of their excessive cost or complexity.

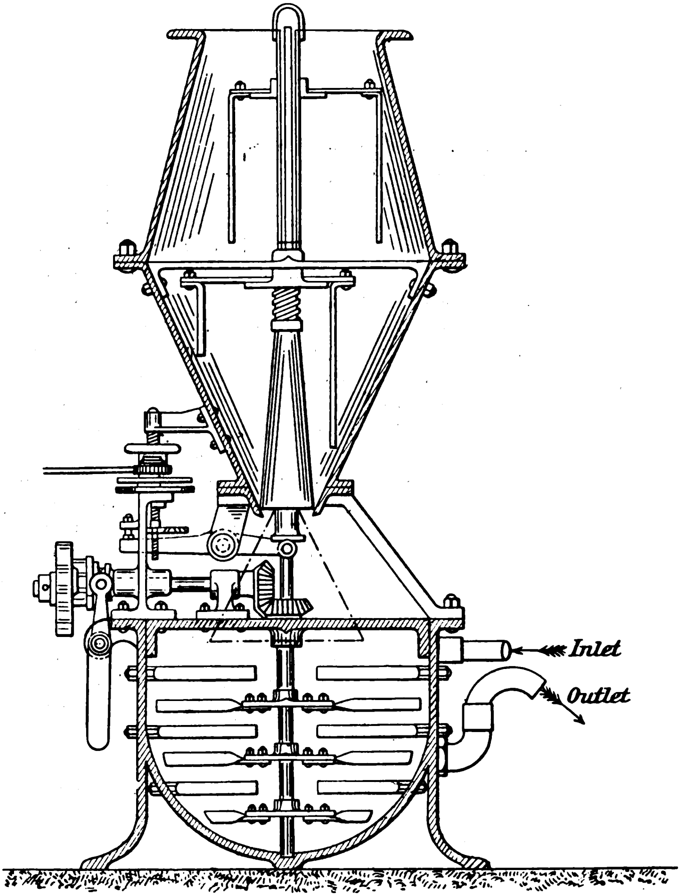


Fig. 146.—Kierby's mixing machine.

(1) Alum, blood, and clay treatment, known as the A. B. C. process.

(2) Lime treatment or lime in conjunction with other chemicals, as
(3) Sulphate of alumina, (4) Sulphate of iron, (5) Perchloride of iron.
(6) The alumino-ferric treatment.
(7) The International process.
(8) The Magnetite process.
(9) The Oxygen process.
(10) The Hermite treatment.
(11) The iron process.
(12) Electrolysis.

278. (1) The *A. B. C. process* was one of the first methods devised for precipitating and clarifying sewage, the constituents being alum, blood, and clay; the blood has been eliminated and charcoal substituted. The tanks used were divided by parallel walls about 10 feet apart, and the treated sewage had to travel round the ends of each wall. If a tank was of any length (about 100 feet), and, say, 30 feet wide, the walls are so arranged that the sewage would have to travel a distance of about 60 feet in passing through a longitudinal distance of 20 feet. The process has been in operation at Aylesbury, Leeds, and other places (at the first named place it is still in use), and the effluent is allowed to pass direct into the river course; it gives a good effluent, and the precipitant is taken from the tanks and sold as manure.

279. (2) The *lime process* is used in many places, principally because the lime is easily obtained and is comparatively cheap, and the precipitant has a good manurial value because of the lime which is in the sludge. It makes more sludge than many of the processes. The lime is reduced by mixers to a milky consistency, and is allowed to drip into the sewage as described above (Art. 276). In order to obtain the lime in this consistency, it is first slaked, then raked over, and any stone or extraneous matter removed; it is then put into a grinding mill; water is added until it is in a finely-divided and creamy condition. The quantity of lime varies from 6 to 12 grains per gallon.

The process should be augmented by passing it over land or through filters, as the lime renders the effluent alkaline, and in such a state is detrimental to fish life.

280. (3) *Lime and sulphate of alumina* is used in many towns. The quantity varies with the sewage on which it is to operate. A general proportion is that of 6 grains of lime with 3 grains of alumina per gallon of sewage. The alumina is used in order to lessen the amount of sludge; it also increases the manurial value of the sludge.

281. (4) *Lime and Sulphate of Iron.*—This is used in the proportion of 4 grains of lime with 1 grain of the sulphate per gallon of sewage. The sulphate of iron is obtained in the crystals in a

dry state, and should be used fresh, before it has time to be converted into ferric sulphate. The crystals are easily dissolved in water; a lead-lined vessel should be used for this purpose.

282. (5) *Perchloride of iron* is also sometimes used in conjunction with the lime or other chemical compounds.

283.—(6) *Alumino-Ferric Treatment.*—Alumino-ferric cakes are placed in a cage in the flow of sewage, which dissolves it in the proportion required. The cage takes the form shown in Fig. 147. As the water increases in depth it comes in contact with a larger area of the alumino-ferric, and thus the quantity of chemical is also increased. The proportion is about 6 grains per gallon of sewage.

284. (7) *International Process.*—The principal precipitant is ferozone, which is a magnetic ferrous carbon; it is the same substance as the polarite used in the filters of this process. The two compounds are treated differently, and have therefore different characteristics, one being partly soluble and the other quite insoluble. Both the polarite and the ferozone contain alum, calcium, sulphate of magnesia, and magnetic oxide of iron.

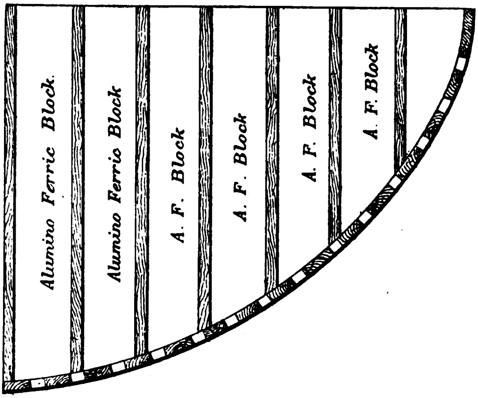


Fig. 147.—Cage.

The soluble portion of the ferozone precipitates slightly, and the magnetic oxide of iron assists in effecting a rapid subsidence; it also acts as an absorbent of the organic matter, and oxygen is given off, which disinfects and deodorises the sewage and sludge.

Polarite is the name given to magnetic oxide of iron after being carbonised in retorts, treated by a patented process and granulated. In its original state it is said to be non-absorbent, but in its manufactured form is absorptive. It is insoluble and not liable to rust; at the same time it is porous and exceedingly hard. It extracts lead and iron from water, and it is claimed that, by means of the polarised oxygen contained in its pores, it becomes a powerful deodoriser, and by a process of inherent combustion burns out the impurities in the water with which it may come in contact.

The ferozone is in lumps, and, being the precipitant, is mixed with the sewage in a similar manner to the soluble chemicals described in the previous articles.

The chemically-treated sewage is thoroughly mixed and passes into tanks, which may be of any of the patterns already described. Precipitation of the solid matter takes place, and the chemical tank or effluent—*i.e.*, the water that leaves the tanks after having passed through this form of chemical treatment, is directed on to what are termed "clarifiers." The clarifiers are small wrought-iron tanks about 6 feet in diameter, but the dimensions vary with the amount of sewage to be treated. The inside consists of a perforated false shelf, which is fixed 12 inches from the floor of the tank. Upon this shelf is placed fine filtering material to a depth of about 15 inches. The effluent enters at a point about 9 inches below the surface of the filtering medium into a channel

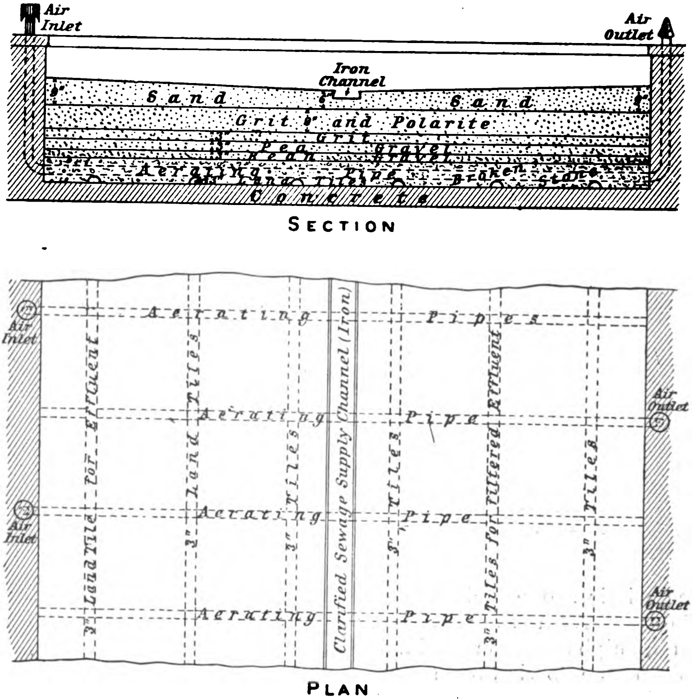


Fig. 148.—Polarite filter.

running round the sides of the tank. The side of this channel being about 3 inches above the level of the bed of sand, acts as a weir for the water to distribute itself slowly and equally on to the beds. The tank is filled to a height of 3 feet above the sand, and the water quickly passes through, and issues from the clarifier as a clear effluent, the small particles not precipitated in the larger tanks being left in the top 3 inches of filter.

The clarifier effluent is then directed through a channel to the polarite filter beds. The depth of the filtering material is about 3 feet. It is composed of material varying in size from grains of sand to that of gravel ¾ inch in diameter. The first 6 to 9 inches is sand, then 9 inches of polarite (about ⅛-inch cubes), which is placed on top of 9 inches of gravel divided into three equal layers, the lowest being of the size of beans, the next above of peas, and the topmost about ⅛ inch diameter. The remaining 9 inches on to the concrete floor is composed of broken stone, which surrounds the 3-inch land tiles laid on the concrete to drain off the filtered effluent. The tiles are about 18 inches apart, and laid with open joints; they are connected with upright ventilators built in the side-walls of the filter beds. These ventilators are for the purpose of aerating the bed and accelerating the working of the filter. Usually 12 inches of water is kept on the top of the bed, which will then discharge at the rate of 2000 gallons per square yard per diem.

285. The clarifiers are cleansed by turning the clarified effluent from one clarifier to the bottom of the one to be cleaned and forcing it upwards through the filtering material, the latter being agitated by rakes worked by hand at the top of the tank, revolving round the centre of the clarifier. The suspended matter, together with the water used for washing the bed, is turned into the sludge tank. They require cleansing very frequently—about five times in three days.

The filter beds are cleansed in a similar manner, the water from one bed being forced through the other. They do not require cleansing oftener than once a week or fortnight.

The loss of head throughout the process—*i.e.*, the difference of level between that of the sewer entering the works and that of the effluent channel discharging into the river—is about 7 feet.

The filter beds are shown in Fig. 148.

This system has been adopted in many towns, with some success.

286. (8) *The Magnetite Process.*—The magnetite filter is very similar to that just described, and the magnetite approximates closely in composition to polarite; the precipitant is aelite. The general treatment is akin to the International process, and therefore need not be further described here.

287. (9) *The Oxygen Process.*—This is a system which has been brought forward by Mr. Adeney, F.I.C., and Mr. Kaye Parry,

M.A., &c. Although it has been used only in small installations, it is an interesting and instructive study in itself and shows how the change from the chemical treatment to the bacteriological was being, perhaps unconsciously, developed.

The object of the proprietors of the patents is to reduce sewage matter to simple and harmless substances by oxidation. As this is brought about by the operations of micro-organisms and not by direct oxidation by the oxygen of the atmosphere, as was formerly supposed, it is explained that certain organisms which live on dead organic matter quickly grow in sewage matter, and will rapidly set up an oxidation of the organic matters and change them into harmless forms, provided that a continuous supply of air is given to all parts of the liquid and that the liquid is kept in a slightly alkaline condition. The organic matter undergoes two distinct operations. In the first stage it is converted into carbonic acid, ammonia, and water; and in the second stage the ammonia is gradually converted into nitric acid. For the complete purification of a sample of 1000 volumes of very foul sewage, it required 1400 volumes of air for the first operation and 1500 for the second, and in a moderate sample of sewage it required a total volume of air equal to a little over 1½ times the volume of the sewage to complete the work of the micro-organisms and obtain a pure water.

In practice the second stage is not necessarily carried out, because the organisms do not absorb the oxygen as quickly as the water, and the water is therefore not deoxygenated, as happens in the first stage.

288. The ordinary process of filtration is simply an artifice or means of supplying air to all parts of sewage continuously during purification by organisms. The sewage, in passing through a filter, 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 sufficiently slowly, the supply of oxygen will be assured for their purification.

It is with the idea of dispensing with these filters that the inventors have brought forward their process.

The sewage is treated in three distinct stages:—(1) Mechanical subsidence, (2) chemical precipitation, and (3) oxidation.

By the first process, the solid matter is removed in tanks or series of tanks by subsidence, without any aid from chemicals; it is hence claimed that solid matter is only one-half the bulk of that obtained in chemical precipitation, and that the manurial value is double that of ordinary chemically-treated sewage sludge. By this process the major portion of the organic matter and all the mineral matter is thrown down.

The second process—viz., chemical precipitation—gives a sludge which contains comparatively little organic matter, while the chemicals used in the precipitation may be recovered for use again on fresh quantities of sewage by means of a patented process. The precipitant is a manganese compound which, in the sludge, is in the form of higher oxides and carbonate, the manganese being separated in its pure form by a patent process. Thus the high cost of manganese compounds does not prevent its use.

The third stage is the direct chemical oxidation by means of manganate of soda. The organic matter left in the sewage and the manganate quickly react upon one another, some of the former being decomposed into carbon dioxide and other harmless bodies—the brown insoluble peroxide of manganese formed subsides to the bottom of the tank. It may easily be recovered, reconverted into manganate of soda, and re-used.

After this treatment the effluent is said to be perfectly free from odour and practically free from suspended matter.

The final state of purification is obtained by the action of micro-organisms, nitrate of soda being added to supply oxygen to them, the organisms having the power of decomposing this substance and abstracting the oxygen they require.

The company state that the works for dealing with the sewage of a town of 100,000 population could probably be arranged in a space of 50 yards by 50 yards.

The sewage also need not be treated entirely at the main outfall, but 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, and no skilled labour. The tanks are of the Dortmund type, which have already been described.

They recommend it as a cheap method of dealing with manufacturers' refuse, such as that from paper-works, bleach and dye works, wool-scouring factories, tanyards, and other works.

It is used with success at the Criminal Lunatic Asylum at Dundrum, Ireland.

289. (10) In the *Hermite process* an antiseptic liquid is poured into the heads of the drains, or is supplied to all houses for the purpose of flushing the drains and sewers instead of with the ordinary clean water. The liquid is produced by passing electricity between zinc and platinum electrodes suspended in sea water, or in a solution of magnesium and sodium chlorides forming nascent oxygen (a powerful deodoriser), which is held in suspension by hypochlorite of magnesia.

290. (11) Another process of purifying or deodorising the sewage in its progress through the sewers is that known as the *iron process*, which was invented by Mr. F. R. Condor, M.I.C.E., of Guildford. The precipitant used is sulphate of iron, known as ferrous sulphate or copperas. The crystals are placed in a perforated cone called a ferrometer, surrounded with water 2 or 3 inches in depth. Water in passing through the ferrometer dissolves the

sulphate, and the solution runs into the sewer and mixes with the sewage. The inventor says, "It provides a means of rendering stable the solution of iron and its salts in a manner which was declared highly impracticable, and allows of the automatic supply of an exactly determined quality of iron where required. It works with unexampled rapidity, utilising the darkness of the drains and sewers and the natural movements of the water supply. It is distinguished from all processes which are adopted to effect precipitation, in the fact that it splits up or resolves into harmless elements the putrescible matters which are the cause of sewage pollution. As a secondary effect it produces a fine deposit, chiefly consisting of mineral matter, which has no tendency to associate with water or to form a semi-fluid or sludge. For equal quantities of matter removed from sewage the deposit formed by the iron process is only from $\frac{1}{8}$ to $\frac{1}{20}$ part of that formed by any existing method. The deposit thus obtained is inoffensive, perfectly manageable, and of appreciable value. Obnoxious smells and sewer gas are not produced below the points where the iron solution is mixed with the sewage. No foul matter collects in the drains below such points, and no cleansing by hand is required. The purchase and preparing of land, the construction of large settling tanks, and the use of steam pumps and other machinery are rendered unnecessary."

The descriptions of these schemes are given with the view of illustrating what has been devised to deodorise the sewage in a fresh condition. It must be evident that there are difficulties in the adoption of either of them, seeing that the sludge would have to be removed from the sewers, and although the matter may be inoffensive it would cause considerable expense and possible danger to whoever might have to see to the cleansing in times of flood. There would be strenuous objection to the idea of allowing the treated sewage to be washed into river courses without the sludge being first removed, and although the theoretical solution may be perfect the practical operation must be condemned on this ground alone.

291. (12) The treatment of sewage by *Electrolysis* is sometimes known as "Webster's process." The sewage at one of the Metropolitan outfall works was operated upon by Mr. Webster for some considerable time. The scheme may not be properly termed a chemical process in the sense of the preceding methods of precipitating; in reality it is so, because the chemical compounds in the sewage itself are operated upon by an electrical current, and are used for its precipitation, deodorisation, and purification.

Cast-iron plates of the commonest quality having been found to give the best results as electrodes are placed in a specially constructed channel through which the sewage is directed. They are placed longitudinally, and the alternate plates are connected with the positive and negative terminals of a dynamo.

When in action the electrical current splits up the constituent parts of the sewage. The soluble organic matter is oxidised and burnt up by the nascent oxygen, and the oxides of chlorine are evolved. This oxidation may be increased if a greater degree of purification is required. The suspended matters and part of the organic matters are removed by precipitation.

The student of chemistry will at once recognise that the process is one of electrolysis.

Sodium, magnesium, and other chlorides are always present in sewage water, and these salts are split into their constituent parts. The chlorine and oxygen combine with the iron of the plates at the positive pole, and through some peculiar operation changes from a hypochlorite of iron to a chloride; this latter is deprived, in its turn, of chlorine, and forms ferrous carbonates and oxides. The presence of the ferrous carbonate in solution is chiefly due to the carbonate of ammonia in the sewage. In samples that are absolutely free from dissolved oxygen the ferrous oxide in the white form is precipitated; after mixing with air it changes to the usual greenish shade. The carbonate of iron changes also to the ferric oxide, and this sometimes changes back again to the ferrous state; thus showing that it has acted as a carrier of oxygen to the organic matter.

In the trials on the sewage at the southern outfall at Crossness various degrees of purification have been obtained, the organic matter being reduced one-half and up to 90 per cent.

Where sewage is treated with chemicals it will be apparent that, with the bases and acids in the sewage, the metal of the chemical will combine and form a precipitate; thus the sludge is considerably increased. Moreover, the precipitate and the chemical effluent in such a process, if left standing in the atmosphere, would produce secondary decomposition; this must be avoided, and it is, therefore, necessary to take further action on both the sludge and the chemical effluent in order to prevent such a result.

In this system the sludge is reduced to a very small amount; the major portion of the organic matter which would produce secondary decomposition is removed. The sewage, after flowing through the channels, is passed through settling tanks, and after the mechanical precipitation or subsidence has taken place, the effluent is found to be quite innocuous, and only contains about 3 grains of suspended matter per gallon, principally as ferrous oxide. If this effluent were passed through a filter bed, and the ferrous oxide and other suspended matter removed, it would be no more chemically pure as regards the organic matter.

Where land is cheap and available, the progress would be regulated to give a much less quantity of organic matter in solution than would be necessary where settling tanks alone are adopted. The subsequent filtration through the land is used to remove the remaining quantity of organic matter before it is allowed to enter a river course.

292. Mr. Webster also provides an electric filter when a higher degree of purification is desired. Alternate layers of sand and coke (free from sulphur) are laid down, the layers of coke being used as electrodes. The effluent is first run through the top layer of sand, in order to remove the matter in suspension. Owing to the presence of nascent oxygen and chlorine, which are given off when the filter is in action, it is impossible for disease germs to propagate.

It is claimed that the bacteria in the sewage are practically all killed after it has passed through this process, and that the effluent is sterile.

The plant necessary for the treatment of 1,000,000 gallons of sewage in 24 hours would be a dynamo giving off 23 kilowatts, or 30 indicated horse-power, provided that 450 tons of iron are laid down as electrodes. The amount of iron consumed per annum is 45 tons, hence the outlay on iron is for a period of ten years.

The figures may be modified, as the amount of iron is in inverse proportion to the horse-power; the larger the amount of iron laid down, the longer it will last, and the cheaper it will be in the end.

293. It would appear from the average of many analyses that it would not be difficult to obtain the following analytical conditions, which are perhaps ideal.

The amount of albuminoid ammonia in an effluent should not exceed 0·06 grain per 70,000 parts. Free ammonia should not be above 0·10 grain per gallon. The oxygen absorbed after being in contact with the effluent at 80° C. for four hours should also not be above 0·50 per 70,000 parts. The Mersey and Irwell Joint Committee and the West Riding Rivers Board allow the effluent to contain 0·10 grain of albuminoid ammonia, and 1·4 grain per gallon of oxygen absorbed (if the effluent should absorb anything under 1 grain it is considered good).

294. The cost of treatment of sewage by chemicals, and labour for a volume of 1,000,000 gallons, is about £3 per day.

Another average estimate of the cost of dealing with the sewage of a population by chemical precipitation and subsequent filtration is thirteen pence per head of population per annum; this includes the annual repayment and interest on tanks and buildings.

295. Where a sewage effluent discharges into a river in which the flow is small compared with that of the effluent, the purification of the latter must be much better than that in the case of an effluent discharging into a river having a larger flow of water.

The river is a self-purifying agent, and may also assist in the purification of the effluent.

Chemical processes have lost much favour in the eyes of engineers, as there is a great difficulty entailed in getting rid of the sludge; farmers do not care for it, and will not, in many cases, have it on their land, and the accumulations have reached such proportions that in some cases it has had to be burnt in refuse destructors. The necessity has, therefore, arisen for a process which will be at once cheap and have a minimum amount of sludge.

296. It is not surprising that the treatment of sewage by bacteriolysis has revolutionised the present systems, even though at present it is only in an experimental stage. It is a process that may be used on every sewage with marked effect. Chemicals are not used, the organic matter is entirely removed, leaving only mineral solids which go to make up the sludge, and this, it must be apparent, is the minimum amount that could possibly be attained.

The theory is so full of possibilities and interest that it will be dealt with in a separate chapter.

297. With reference to the systems of Broad Irrigation and Intermittent Downward Filtration without the addition of chemical precipitation, the micro-organisms have been allowed to work out the destruction of the organic matter in much the same way that nature provides; this is in accord with the bacterial treatment. The unsuitability of land and the difficulty of obtaining an area capable of receiving a continuous supply of sewage, or sufficient in size to allow of portions having the requisite time for rest, have led engineers and chemists to find a sewage purification method which can be effectively carried out on a small area.

It was thought that, if the solids were removed by subsidence in tanks, this would give the land a better opportunity of operating on the liquid portion of the sewage. This, however, has not served the purpose, as the point missed was the "resting" of the land in order that it might become aerated. If the liquid could have been separated and purified the land would easily deal with the solid matter. This, however, would be impossible. Recourse was had to chemicals which were to be used as antiseptics, or for the purpose of throwing down the solid matter in a state acceptable to farmers. Certain of the chemicals killed or paralysed the germs which might otherwise have assisted in consuming the organic matter. Most of the solid matter was removed, but the cost of precipitating it and the difficulty in the disposing of the sludge have been prohibitive drawbacks.

Other chemicals rendered the sludge unfit for manurial purposes, and there has been great difficulty in obtaining a definite ratio of the amount of chemical that would precipitate the solid matter in the sewage.

Lime has been used more than any other substance. It probably gives a greater quantity of sludge for a given sewage than any other precipitant, but it is cheap and more easily obtainable.

It is possible to add too little lime to the sewage, and it is also just as possible, to add too large a quantity. Too much lime has the same effect on the sewage as if there had been just enough; the extra quantity is wasted, as it simply increases the quantities of the sludge.

There are similar objections to the use of lime in conjunction with ferrous and ferric sulphates. Iron is always to be found in the effluent, owing to the solubility of the iron salts. Lime, however, by itself or in combination, is perhaps the most suitable, as it reduces organic structures, and combines with the carbonic acid produced by this decomposition in the presence of air; thus forming the initial stage necessary for the purpose of nitrification.

Filtration over or through land to act as a final and complete purifier of the chemical effluents is an absolute essential, as it has been proved that chemicals only remove the suspended portion of solid matter in the sewage, together with a very small portion only of the putrescible soluble constituents which go to form the manurial value of the sewage. These constituents can only be removed by the process of nitrification—*i.e.*, through land or some specially-designed filters.

298. The *Liernur Pneumatic Sewerage System* is the invention of Captain Liernur, a Dutch engineer, and it is in operation in its most up-to-date state at Trouville-sur-Mer in France.

The system is operated differently from Shone's; instead of compressed air being used to force the sewage forward, a vacuum is formed which draws or inhales the sewage through the sewers.

This inhalation is in action right through all sewers and to the house connections. The excreta and water from W.C.'s, sinks, baths, &c., discharge into a soil pipe which has its outlet in a small specially-designed hermetically-sealed chamber at the foot of the soil pipe, which is ventilated above the roof in the ordinary manner. The outlet from this chamber is a cast-iron tube about 3 inches diameter, and for about 20 or 30 feet it has a natural fall of about 1 in 16 or 20; here there is placed a syphon and compensator (an enlargement of the pipe to ensure the syphon is not untrapped when the vacuum pipe has access to the tube), the tube here rises vertically for a short distance and then turns and falls to the sewer in the street. On this portion a valve is placed, so that the house can be disconnected from the system.

The town is divided into districts, and in each district is placed a reservoir tank in a convenient position to receive the drains from the houses and sewers. It is not necessary that the sewers should gravitate to the reservoir, and they need but follow the surface of the road at a depth of about 3 feet.

A man goes to each reservoir once a day and causes each house drain and sewer to discharge into the tank. The operation is simple. The valves on the drains communicating with the tank are all shut down, then the valve on the vacuum pipe is opened, and at once the vacuum is in connection with the tank. The valves on the drains are in turn now opened, and immediately the atmospheric air rushes through the ventilators of the soil pipes and causes the contents of the chambers to each house to be discharged and the sewage to flow through the pipes and sewers at a rate of from 6 to 8 feet per second to the tank. When the tank is full, the vacuum pipe is shut off, as are also the drains; the air pipe to the tank is then opened, and the valve in the connection from the tank to the main sewer which discharges at the works is opened; this main sewer being also under depression, the contents of the reservoirs are at once discharged and conveyed to the sewage works.

The vacuum is at a pressure of from one-fifth to one-half of an atmosphere. The design of the chambers is so arranged that the vacuum cannot unsyphon the traps, and the degree of vacuum is equal whatever the length of the sewer or distance of the house from the reservoir (up to, at any rate, 600 yards); in consequence, the receptacle with the greatest quantity of sewage is discharged into the sewers first.

There is no flushing required, neither are there any manholes and ventilating holes necessary, and there cannot, of course, be any offensive smells.

One of the objects is to have the sewage brought to the works with as little water as possible; the disposal of the sewage at the works is a patented process—it consists of sterilising the sewage by mixing with it sulphuric acid, then concentrating by submitting it to a temperature of 212° F. in a special apparatus.

The excreta, &c., is thus made into manure powder, equal in weight to 90 lbs. per head per annum, containing 10 per cent. nitrogen, 5 per cent. phosphoric acid, 5 per cent. potash, and 18 per cent. hygroscopic moisture.

The cost of the system, apart from the disposal works, is about 25s. per head for towns with small populations; it is considerably less in proportion when the towns are large and dense.

CHAPTER XVI.

BACTERIOLYSIS.

299. MR. DIBDIN a few years ago stated that the "antiseptic processes of sewage treatment which it is pretended produce a sterile effluent are wrong in principle;" that "chemicals destroyed the organisms required for the work of purification of the sewage;" and that "they might render the sewage inodorous, but as soon as the chemicals became diluted putrefaction sets in again."

It was by the publication of the report of the Massachusetts State Board of Health, who carried out a large number of experiments on sewage purification during the years 1889-90, that the process of bacteriolysis was, so to speak, discovered. The results given stirred the minds of both chemists and engineers, and among them Mr Dibdin, chemist to the London County Council, who succeeded in setting up a filter bed at the Barking outfall of the Metropolitan sewers on the lines suggested by that report. During the course of a series of experiments certain peculiarities were noticed in the effluents compared with the original sewage, which, after careful investigation, resulted in the erection of a small set of bacterial beds both at Barking and at Sutton, Surrey, a description of which is given in Art. 306.

300. The discovery that sewage was purified by the action of micro-organisms, and not, as was supposed, by the oxidising power of the air in contact with it, was due originally to three eminent men. Schloessing, in France, discovered that sewage passing through a bed of baked sand and burnt clay became purified. When chloroform was added the purification ceased, and when it was removed purification commenced again. Hence he concluded that living organisms were at work. Warington, in England, as a result of a series of experiments, concluded that nitrification was due to living organisms; and Frankland, another well-known English chemist, believed that the purification was due to a process of oxidation producing carbonic acid and nitric acid, and that a continual aeration of the soil was necessary.

It is not the object of the author to discover the real originator of the bacterial treatment, as there are several claimants to the honour; but it will be seen that the year 1892 may be looked upon as the year of "emancipation" or freedom from the use of chemicals as a precipitant.

301. Mr. S. R. Lowcock early in 1892 carried out certain experiments on a sewage. He constructed a filter which was designed

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. The results are given in a paper published in the *Proceedings Inst. C.E.*, vol. cxv. Briefly, his process was as follows:—

On the bottom of a tank, 7 feet 6 inches square, were placed earthenware pipes, butt-jointed, in order to carry the water from the filter, as has been before described. A 6-inch layer of broken stone ($\frac{5}{8}$ inch) covered the pipes, and on the top was placed another layer 15 inches deep, composed of the natural soil of the district (a stiff clay), ashes, and building sand. Here a $\frac{3}{4}$-inch pipe was laid, the pipe being perforated every 6 inches with holes $\frac{1}{16}$ inch in diameter; one end was stopped and the other connected to an air compressor. Then, material in exact duplicate of that below the pipe was laid above it, the total depth being 3 feet 6 inches.

The air compressor was set to work and crude sewage roughly screened at the rate of 263,780 gallons per acre per day turned evenly on to the filter. It worked for 19 days, but at the end of that period the filter was only discharging at the rate of 100,000 gallons per acre per day. The effluent was clear and odourless, and there was a reduction in the ammonias of 98·93 per cent. The air pressure was at the rate of 0·6 inch water, and the volume 2·99 cubic feet to 1 cubic foot of sewage. During a run of 57 days the flow was stopped on the nineteenth day and the surface dried and raked over; 263,780 gallons per acre per day were again run on to the filter, and at the end of the forty-seventh day the surface became choked, the supply having got down to 66,900 gallons per acre per day. The top 2 inches of soil was taken off and new soil put in its place, the original quantity was allowed to run on to the filter, but on the fifty-fourth day it had to be reduced, and on the fifty-seventh day the air-supply was stopped; on the sixty-fourth day the filter was practically thoroughly choked—the effluent became discoloured on the day the air-supply was stopped, fungoid growth made its appearance, and the effluent had a slight smell.

Later the filter was altered, and, in place of clay, sand and ashes (fine broken stone) was substituted, on top of which was a layer of fine sand; the chemical effluent from a precipitating tank was tried. The air supply was from a blower, and the chemical effluent so screened that practically no matter in suspension was allowed to get on to the filter. On the 8th February, 1893, the rate of flow was 484,000 gallons per acre per day; on the 14th it was reduced to 373,890 gallons, and on the 15th to 178,390 gallons. The surface became thinly coated with a film, but after working four days it cleared itself to some extent and the flow was raised to 263,780 gallons; on the 22nd February it was again increased, after the surface had been raked over, and on the 3rd, 11th, and 18th March it was also raked, but on the 21st the surface became so dirty that the supply was stopped; it had been working 44 days. Mr. Lowcock gives a diagram showing that, although the ammonias in the tank effluent were increasing considerably, the ammonias in the filtered effluent continued to decrease. None of these latter effluents, kept in a warm room, showed any signs of putrefaction.

The experiments demonstrated, among other things, the fact that the filter worked better after having been in continued operation a few days, which agreed with the findings of the Massachusetts experiments.

302. In the same year (1892), Mr. Scott Moncrieff made another experiment, but in this case the solids of the sewage were not removed, even by screening. He claims (and apparently has the right to do so) to be the first to recognise 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.

His first experiment was a bed 10 feet long by 2 feet 6 inches wide by 3 feet deep. All sewage, except grease, from his house (containing 12 persons) finds its way into the bottom of this bed, which has a false bottom; the flow passes through 14 inches of successive layers of flint, coke, and gravel, till it reaches the overflow pipe, which is about 2 inches below the level of the invert of the drain. Instead of this filter becoming choked, he found that the effluent improved in quality, and the whole process was continued for months together without causing any nuisance.

From these experiments he developed the tanks and filters shown in Fig. 149. The sewage flows through the chamber A and the screen B, which is at the bottom of a mass of rough stone. This tank is termed the first cultivation tank. It is here he finds that the organic matter is liquefied, and, after such liquefaction takes place, other changes have occurred due, first, to the action of the micro-organisms which come in with the sewage and use up the available oxygen in the lower layers of the tank; and second, from the work of the anaerobic varieties, which work for the most part in the zone where the oxygen has disappeared. The most prominent change which takes place is the conversion of various nitrogenous substances into the simpler forms of nitrogen—as free ammonia. In order to carry on this process to the fullest capacity of the anaerobic organisms, the effluent from the first cultivation tank is then discharged intermittently over a series of superimposed filters, each of which naturally contains a survival of the 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 intermittent supply is obtained by a series of tippers which are shown in the enlarged section of the filter or second cultivation bed.

303. This system appears to the author to be on thoroughly scientific lines. The sewage has a chance given it to precipitate the mineral solids in the bottom of the first cultivation bed; it would be better if the grating occupied the full width of the tank in order to give this matter every opportunity to subside to the floor. If the matter passes into the cultivation bed, the capacity of the bed must in time become very much reduced; the organisms cannot be expected to work the liquefaction of all such matter, and in the sewage of a manufacturing town (to which any process of purification must be adapted to become successful in a popular sense), the proportion of mineral matter to organic matter is quite out of proportion to that from a residential district. The aerobic or second cultivation beds also must give excellent results, as the air has ample access to the medium of the beds.

The depth or head is excessive, but, if the results are in proportion, this is a small matter.

304. Bacterial action on sewage converts the organic matter into, principally, ammonia, marsh gas, and nitrates. These compounds in themselves are harmless substances, and are produced by certain micro-organisms—only observable by a powerful microscope—many millions of which may be found in a few drops of the liquid. These micro-organisms differ in shape. Some are long and thin, others short and (comparatively) stout rods, and others again are like dots. Each form may occur separately or in groups arranged in pairs, short threads or long threads; some again are curved or spiral. Even drinking water—clear as crystal to the naked eye—will, on being examined, be found to hold certain micro-organisms.

It is possible to obtain pure cultivations of these micro-organisms, as each thrives best in special media and under special conditions.

Sewage and other organic refuse is resolvable by bacteria into simpler compounds, each phase of the breaking-down process being effected by distinct sets or groups of bacterial species. The final stage consists of nitrification, which comprises several distinct operations, and is, for the most part, carried out at sites near to, but separate from, those where the earlier phases are in operation. The ammonia is first oxidised to nitrous acid, or to a nitrite by one group or, rather, by a predominant species of the group, while the further oxidation to nitrates is effected by another distinct micro-organism or group of micro-organisms.

The main supply of the organic refuse is on the surface soil, and the first changes are effected by the bacteria which require atmospheric oxygen for their existence, and were hence classed as "aerobic" forms by Pasteur. Lower in the soil, away from the access of atmospheric oxygen, the changes are brought about by bacteria which are independent of such air, as the oxygen they need is obtained from the organic substances themselves; hence they are grouped as "anaerobic." Intermediate between these are forms which can exist under either condition. These are known as "facultatively" aerobic or anaerobic bacteria.

305. Dr. Frankland thus explained the operative processes at the Sanitary Institute meeting, held in Southampton in September, 1899:—

"The recent experimental work on the bacterial treatment of sewage . . . shows most conclusively that the best results are achieved by separating the phases in which the bacterial purification takes place, allotting distinct places to the anaerobic and the aerobic organisms respectively engaged on the work.

"The anaerobic bacteria are supplied along with the sewage, and practically no difficulty arises in retaining their services on the works, beyond that of providing them with space and time in which to carry on their labours. The aerobic bacteria, however, demand air, in addition to space and time, and if this air be not provided in sufficient quantity, they go on strike, and leave the works, their place being taken by their less-exacting anaerobic brothers, who are, however, unable to finish the work of purification.

"There is, then, the constant tendency for the overflow of the anaerobic bacteria into the aerobic department of the works, if there be any stinting of the air in the latter. In order, therefore, to insure the services of the aerobic bacteria being retained on the premises, it is desirable to provide for the aerobic bacteria at least two workshops through which the sewage, on coming from the anaerobic department, is made to pass. The first of these aerobic workshops it may be difficult to provide with adequate ventilation, the result being that both anaerobic and aerobic bacteria will here be found competing with each other, and that the aerobic organisms will be unable to complete the work of purification. The sewage, however, on passing into the second and better ventilated workshop, will there fall almost exclusively into the hands of aerobic bacteria, which it will, under proper management, leave as an inodorous, almost pellucid liquid incapable of putrefaction."

306. The Sutton bacterial bed, designed by Mr. Dibdin, was made 1 acre in area, and was composed of a layer of coke breeze 3 feet thick, with a thin layer of sand on the top to keep the coke from floating. The bottom of the bed was provided with perforated pipes laid herring-bone fashion. The bed was filled with effluent from subsidence tanks, and allowed to stand for two hours, then it was drained off. The cycle of operations took seven hours; it was repeated during six days, and given a complete rest of twenty-four hours. In this way the beds were capable of treating 1,000,000 gallons per diem.

The reduction of organic matter averaged about 80 per cent. The effluent in every case from the bed was entirely free from putrescible matter, and the smell was that of fresh garden mould. The only point that had to be carefully watched was 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.

Wherever these beds have been put down the sewage has a preliminary screening. Automatic gearing is provided so as to allow of the discharge of the sewage on to the bed during one hour to fill, two hours to stand, one hour to empty, and three hours to rest and aerate.

Care is exercised that nothing above the size of a walnut forms part of the ballast or breeze, and that all dust and similar material should be excluded.

307. Drs. Clowes and Houston, Chemists to the London County Council, have been experimenting over a period of ten months with crude sewage on coke beds at Crossness during 1899. They put down two beds, a "primary" and a "secondary" in series; these were 26 square yards in area, and the depth was 12 feet; the depth of a third was 6 feet, this acted as a single bed, and was filled to a depth of 4 feet with coke of the size of walnuts.

The cycle of operations was 12 hours; filling, 7 minutes; resting, 3 hours; emptying, 1 hour; aeration, 8 hours; with an additional aeration and rest of one day in seven. The conclusions arrived at are well worth recording. It was found that the beds did not become fully matured so as to exert the full purifying action on the sewage until some time after they began working; in this case the best results were obtained after four weeks of operation.

The effluent from the single bed remained free from objectionable odour when kept in open or closed vessels, provided the bacteria present in it were not removed or killed by subsequent treatment. The surface of the coke became partially covered with soft matter, which consisted of fine particles of coke with some fine sand, woody and vegetable tissue, cotton and woollen fibres and diatoms. This soft fibre did not appear to be removed by aeration, and they concluded that it might be kept away by previous sedimentation. They also say, in effect, that the beds of coke below this film were as clear as if it had just been placed in position.

They varied their experiments by passing the sewage through a 6-feet bed of coke.

The amount of sewage successfully treated per day amounted to 555,000 gallons per acre per diem for the 4-feet bed, and 832,500 gallons for the 6-feet bed. This represented in each case one filling per day (two fillings per day were put through the beds during six months, corresponding to 1,665,000 gallons per acre per diem for the 6-feet coke bed). These amounts became reduced after ten months' working to 370,000 gallons per acre per day for the 4-feet bed, and 673,400 gallons per day for the 6-feet bed.

Dr. Clowes infers that 3,500,000 gallons per acre per day could be properly treated through a coke bed of 13 feet in depth.

The single bed removed all suspended matter, and 51·3 per cent. of the dissolved putrescible oxidisable matter; the secondary process effected a further purification of 19·3 per cent.

The effluent is in no way harmful to fish, as these live and thrive in it, which is not the case with chemically treated effluents, as these are lacking in dissolved oxygen.

Dr. Houston says that the bacteria are not reduced in number. His report shows that the presence of many of the bacteria in the effluent is possibly unobjectionable, and is probably necessary for the purpose of continuing the purification of the effluent when it has flowed into the river, but it further shows that some of the bacteria whose presence might be looked upon as undesirable in drinking water pass through coke beds.

308. A conclusion may be come to with regard to the report that the purification is not any better after passing through the 6-feet bed or the 13-feet bed than it was after passing through the 4-feet bed. This conclusion has been arrived at in other places, and, apparently, if the bed were only a few inches deep, the purification would be quite as good as that for 13 feet, but the capacity of the filter would be proportionately less, of course. This is borne out by the land purification of sewage under a broad irrigation scheme. The top soil to a depth of 12 inches is a bacterial bed, but because it is not drained and ventilated, it becomes choked, and cannot work without a long rest.

309. Mr. Dibdin, with whom is associated Mr. Thudichum, has put down experimental bacterial beds at Leeds; the crude sewage, after a passage through settling tanks without any chemical treatment, is allowed to fill the beds. The cycle of operations is similar to that at Sutton, and the degree of purification up to September, 1899, was highly satisfactory, corresponding, as it did, with 85 to 92 per cent. reduction of organic matter.

310. The sewage which is to be dealt with on bacterial beds must not contain any matter injurious to the micro-organisms. It is, therefore, necessary that the refuse from manufactories should be examined, and all antiseptics and germicides, such as chlorine in its free state, hypochlorites, &c., should not be allowed to enter the sewer. This does not prohibit the disinfection of houses, &c., after cases of infectious disease, because the quantity of disinfectant would be small compared with the volume of sewage. The disinfection of drains and sewers may be carried out by oxidisers such as permanganate of potash, which is destroyed in doing its work, and cannot, therefore, act as an antiseptic; this applied moderately is not a steriliser, but merely a deodoriser, and would in reality

assist in the purification of the sewage. The sewage should also arrive at the outfall without being too alkaline or too acid. Sand and grit, together with road refuse, such as particles of straw, wood, paper, &c., should also be kept out of the sewers as far as possible. Manufacturers who have a large quantity of refuse of a character that would be deleterious to the action of bacterial beds, should be required to distribute the quantity by discharging it evenly over the 24 hours of the day by providing tanks and screens. Such a provision would also be a means of materially lessening the solid matter, such as shoddy refuse and wool fibre from scouring mills, &c. The sludge they would have to get rid of by the most suitable method.

311. By a procedure of this kind the acidity, alkalinity, &c., might neutralise each other, or bear such a small proportion to the general body of sewage, that it would not operate against the efficiency of the beds. This method of diluting the sewage has been found to work in a very satisfactory manner.

312. The latest developments of the Dibdin series of bacterial beds are:—(1) The crude sewage passes through a preliminary subsidence in tanks; (2) it is then passed on to a bed of coarse stone having large crevices, in order that the large suspended solids should have access to the material below the surface, where the organisms may work in the dark; (3) The effluent is then passed on to a fine bed, where the liquid is divided into thin films, so as to provide a large surface for the activity of the organisms. The first bed may be composed of material of any description in lumps of about 3 inches in diameter that may be in the neighbourhood. The second bed would be composed of finer material—that is, of fragments—about ½ inch to ⅛ inch in diameter.

The first bed is called the "primary," and the second is termed the "secondary," the object being to equalise the work, the primary bed, being of large material, enables the large solids to enter into the centre, and may there be operated upon by the organisms; the secondary bed, dividing the liquid into thin films, permit oxygen to be supplied to the organism or organisms which complete the purification.

313. If the subsoil in which it is proposed to construct the beds be composed of clay, it may be excavated into the form of a tank, and the sides formed with puddled clay. The excavated clay could be burnt, and made into ballast. The beds may be of granite, flint, slate, coal, coke, cinders, gravel, &c.; each will give equally good results for the time being.

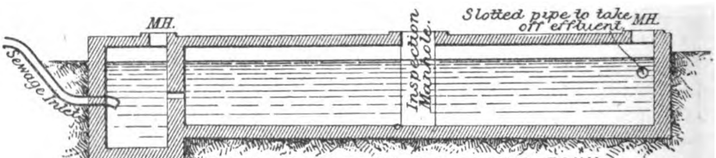
314. The beds, however, should have the greatest possible capacity combined with the greatest possible efficiency with respect to purification.

Cinder beds give a capacity when new of about 50 per cent. of the capacity of the bed without the material. But they almost immediately after being used reduce down to 33 per cent., and later on to about 20 per cent. The bed will be seen to be lowered with the first filling; this is due to the settling down of the material into its position, but the further reduction is due to wear, consolidation, and the adherence of the mineral and other matter to the material of the bed.

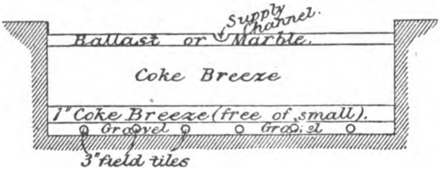
The harder the material the less must be the wear, and consequently the capacity will be kept higher for a longer period.

The capacity of the beds after a long period of working has not been defined with any degree of certainty in the case of sewage from manufacturing towns, the sewage from which, as will be seen from the analyses in Arts. 240 and 320, contains three and four times more mineral matter than domestic sewage.

315. In Art. 179 is described the state of a sewage tank built in 1869, which for nineteen years had received sewage continuously without ever having had any sludge removed from it. The tank is still in operation at the Walton-on-the-Hill Sewage Farm, near Liverpool. It is 100 feet long and 33 feet wide, there being at that time about 6 feet of sewage. It was altered in 1888, as the capacity was not large enough. Here was a striking example of the working of a "septic" tank about to be described, but, to the author (for whom bacteriology was an unknown science), the fact of there being practically no sludge in the tank was at the time considered to be remarkable. There was no further thought paid to it, for the farm was working well and the sewage was easily and perfectly purified.



SKETCH SECTION OF SEPTIC TANK.



FILTER IN CONNECTION
.WITH SEPTIC TANK.

Figs. 150 and 151.

316. The septic tank was designed by Mr. Cameron, the city surveyor of Exeter, and the first installation was put down at Belle Isle, near that city. The sewage is first received into a

sedimentation tank, which is small compared with the main tank, of which it forms a part. Here all road detritus and mineral matter are deposited. The sewage then passes into a tank entirely covered in. There are manholes, but these are hermetically sealed. The sewage enters the tank (Fig. 150) about 3 feet below the level of the water in the tank, the outlet consisting of a pipe with perforated holes is about 2 feet below the level of the water, so that there is practically an entire exclusion of air and light. This then is the place where the anaerobic germs will work. The speed of the sewage through the tank is at the rate of 0·50 feet per minute.

317. The effluent is passed into a shallow aerating trough, over the sides of which it falls in thin sheets into channels leading to distributing wells, from whence it is directed on to aerobic beds, a section of one of which is shown in Fig. 151. The cycle of operations is similar to those at Sutton, Barking, and other places. The beds are worked automatically. The aerobic germs are given full play and encouragement to complete the nitrification of the ammonias and ammonium compounds in the effluent just as the anaerobic germs have been assisted in their work of breaking up the organic compounds into simpler ones, and these in turn into water, gases, and liquids of simple forms.

The sewage experimented upon was from a population of 1500 persons. The dry weather flow was tested to be 35,000 gallons, but the average during the year was at the rate of 54,000 gallons per diem. The tank was 64 feet 10 inches long 18 feet wide, and the depth varied between 7 feet and 7 feet 9 inches. The capacity was about 8500 cubic feet. The flow of sewage being at the rate of 6 cubic feet per minute, it would take 1425 minutes before any individual particle issued from the outlet end. The sectional area = 138 sup. feet.

318. Let D = velocity of inlet in cubic feet per minute,
A = sectional area in superficial feet per minute.

$$\text{Then } \frac{D}{A} = v = \text{velocity in feet per minute through tank;}$$

$$\therefore\ v = \frac{6}{138} = \frac{1}{23} = \frac{1}{2} \text{ inch nearly per minute.}$$

But the flow would be at twice this rate during a portion of the day; hence 1 inch per minute would represent the flow during this period.

After the tank has been working some time there is a scum formed on the top of the liquid; this varies in thickness according to the weather: in summer it is only about 1 inch thick, but in winter it may reach 4 inches.

319. The sediment collected at the bottom of the tank during 13 or 14 months' working was found to be equal to 66½ cubic yards; it was considerably swollen by gaseous matter, which is

formed during the decomposition of the organic matter still adhering to the deposit. The greater portion of this deposit would rise to the surface owing to the quantity of gas contained in it; the gases escape, and the residue, being heavier than water, returns to the bottom. The rising and sinking of this matter means more washing of the matter, and consequently the detritus is reduced to an inert and inoffensive ash.

The analysis of the deposit is as follows:—

Moisture, ...	88·14 per cent.
Mineral matter, ...	7·91 ,,
Loss on ignition, ...	3·95 ,,
	100·00

The quantity of sewage passed through the tank was, during this period, equal to 20,250,000 gallons approximately.

The solid matter in the deposit amounts to 4·3 grains per gallon; adding 0·2 grain per gallon for the solid matter in the scum at the top of the water, the total would be 4·5 grains per gallon. Therefore the total solid dry matter was 5½ tons, two-thirds of which was mineral matter, the remaining third being water of hydration, carbonic acid gas, and a little organic matter not decomposed.

320. Messrs. Dibdin and Thudichum made a most exhaustive examination of the working; they found the sewage entering the tank, collected over 24-hour periods, to contain 14·5 grains per gallon of organic matter and 10 grains of mineral matter. Thus, the amount of matter that has disappeared is equal to 20 grains.

Sewage.		Effluent.		Difference.		
Grains per gallon.		Grains per gallon.		Grains per gallon.		
Organic.	Mineral.	Organic.	Mineral.	Organic.	Mineral.	Total.
14·5	10·00	1·5	3·00	13·00	7·00	20

This difference is equal to 81 per cent. of the total solid matter.

The quantity of sludge represented by 24·5 grains per gallon would be, in 20,250,000 gallons, equal to 31½ tons; this has been reduced to 5½ tons.

No other known system outside bacteriology is capable of removing such a proportion of solid matter. If chemicals had been used, the sludge would have been equal to about 45 tons.

With the septic tank are provided beds similar to those which are called "secondary." It is said that the septic tank which is provided for the normal and average daily dry-weather flow will work equally satisfactory when the volume of water is increased three times. Neither will this form of tanks nor the beds, for a temporary flow of this character, be found to deteriorate the working. It has been said that an excessive quantity improves the working; in any case, the efficiency is but very slightly impaired, and would immediately regain its normal condition.

321. It will be noticed that this system of bacteriolysis not only reduces the organic matter, but the mineral matter also, and it would be interesting to know what the minerals were that are reducible and what are not.

322. Most elaborate experiments have been made on the sewage works at Salford and Manchester. At Salford, the borough engineer is laying out several acres of land with coke or cinder filters. There will be a preliminary subsidence of the sludge or suspended matter in open tanks, and the effluent will be passed through a series of pipes which will distribute the water in showers; thus it will reach the bed in drops. It is expected that more air will be taken into the beds, thereby assisting in the purification; air pipes are being freely distributed through the beds in order that they may be thoroughly ventilated.

323. Mr. Candy, who is intimately connected with the International process already described (Art. 284), has brought out a bed, which is to work under anaerobic conditions, to replace the septic tank. He says a tank cannot have so powerful a bacterial action on sewage as a bacterial bed. He uses a preliminary detritus tank, from which the sewage is passed on to an "anaerobic sludge-digesting bed"—this is formed with large stones, clinkers, ballast, &c., or any coarse material which allows the sewage liquid to pass through quickly. In the middle of this coarse material a conduit for the even distribution of the sewage is placed. A layer of about 6 inches of fine material is laid over the whole in order to keep air out of the bed. The effluent taken from this bed is passed by a tipping arrangement into pipes connected to radiating arms worked on the principle of Barker's mill. The effluent is thus sprinkled in drops on to a second bed, taking with it more air than there would be if the effluent had simply been poured on to it. This bed is for the working of the aerobic germs, which require as much oxygen as possible; it is constructed with small material similar to the aerobic beds already described.

Aerobic beds are composed of material such as coke or cinders, because they are porous and are more likely to retain the oxygen than harder and non-porous material, and the size is such as would pass through a ½-inch screen, and then through a ⅛-inch screen to remove the dust.

324. The present requirements of the Local Government Board with respect to the treatment of storm water are—(1) that two volumes of storm water, *plus* the normal sewage, must be treated as sewage proper; (2) an additional three volumes must receive special

treatment, either by a filter used for that purpose only or by passing it over an area of land which is to be used solely for the treatment of this water; (3) where a separate system is in existence, and where the sewage is from domestic sources only, the volume of sewage and storm water to be treated as sewage proper may be reduced to twice the dry-weather flow instead of three times [see (1)]; (4) where an exceptionally pure effluent is to be obtained, this is not to be applicable; (5) the excess of this up to six times the dry-weather flow must be treated as in the combined system; (6) in cases where trade refuse is allowed to enter the sewers, 10 per cent. must be added to the dry-weather flow before the calculations are made; (7) where trade effluents are to be taken into the sewers, the approximate quantity must be ascertained; (8) the net capacity of the bacterial beds must be one-third of the gross capacity when settling tanks are provided for the removal of scum and mineral matter; should no tanks be provided for such removal, the capacity must be equal to one-fourth; (9) three fillings are permitted per day of 24 hours; (10) the suggested depth of the bed is 4 feet 6 inches; (11) secondary beds must be of the same capacity as the primary beds; (12) the beds for the excess flow over three times the ordinary flow may be allowed to pass the water through at the rate of 500 gallons per square yard.

325. The following formulæ for calculating the exact area of primary, secondary, and storm-water beds may be constructed thus:—

Let the unit of population be 1000. The sewage in number of gallons per head $= x$.

$x = 15$ for residential population, as suggested in Art. 243.

The depth of filters $= y =$ 4 ft. 6 ins., or any depth that may be desired.

$$\text{The area of primary bed} = \frac{1000x \times 3 \times 3}{y \times 6{\cdot}23 \times 9 \times 4840 \times 3}$$

$$= \frac{0{\cdot}01105x}{y} \text{ acre.} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$\text{Area of secondary bed} = \frac{0{\cdot}01105x}{y} \text{ acre.} \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

$$\text{Area of storm-water beds} = \frac{1000 \times x \times 3}{4840 \times 500} = {\cdot}00434x \text{ acre.} \; . \; . \quad (3)$$

If trade refuse is allowed into the sewers, the value x will vary in the areas (1), (2), and (3), thus:—

Let $z =$ the approximate quantity of trade refuse liquors that is to enter the sewers per head of population in a regular quantity throughout the 24 hours (see Arts. 234 and 310). Then

$$\text{Area of primary bed} = \frac{0{\cdot}01105\left\{(x+z)+\left(\frac{x+z}{10}\right)\right\}}{y} \text{ acre.} \qquad (4)$$

$$\text{Area of secondary bed} = (4).$$

$$\text{Area of storm-water beds} = {\cdot}00434\left\{(x+z)+\left(\frac{x+z}{10}\right)\right\} \text{ acre.}$$

In addition to this area of beds there should be provided tanks for preliminary sedimentation.

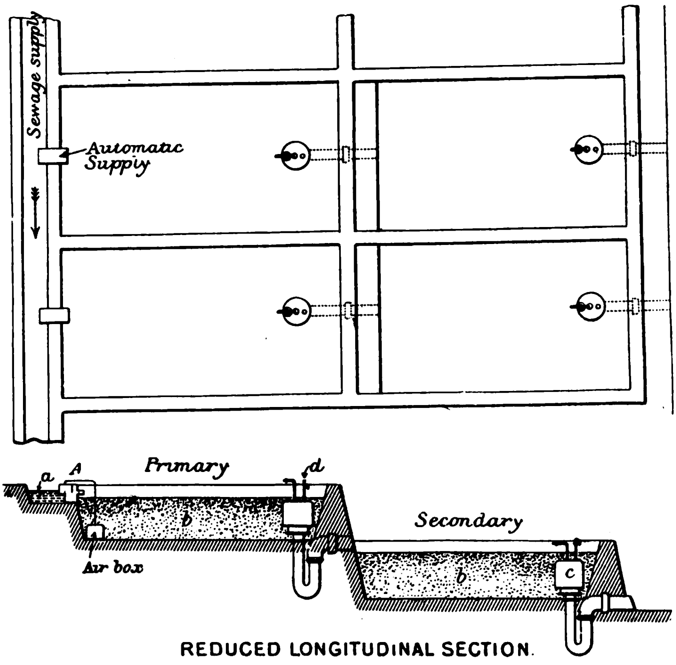


Fig. 152.—Adam's Automatic apparatus.

326. In connection with these processes there are continuously brought forward improvements in details—*e.g.*, Messrs Adams, of York, have their flushing syphons in operation at Sutton, which are to discharge the water from the beds in a short space of time, and they are said to be working satisfactorily. Fig. 152 shows their automatic supply and cut-off and automatic-timed discharge. Each bed will fill, stand, empty, stand, and refill automatically. Any one bed of a series may be put out of work if desired. The sewage flows on to the primary bed through chamber A. When the bed is filling the water encloses air in air

box, and when the bed is full this air stops the passage of the sewage through chamber A, until the bed is released of its water by syphon *c*. This syphon discharges after a certain fixed time, the water encloses air in a chamber, and this is allowed to be discharged by the tap *d*. When the air is so discharged the syphon operates, and allows the effluent to be distributed on to the secondary bed. In a similar manner the bed is rested, and the chamber A is allowed to work again.

Messrs. J. Stone & Co. have also an automatic apparatus, which is worked by floats and levers connected with valves.

327. Colonel G. E. Waring, M.Inst.C.E., experimented in America on somewhat the same lines as Mr Lowcock adopted in this country, and was completely successful in attaining, in some instances, a purification of 99·08 per cent., and an average of 92·5 per cent. He passes crude sewage through a filter until it is full; the flow is then diverted to a second filter; and air is pumped into the first until oxidation of the organic matter is effected. He found that one acre would purify the sewage from 10,000 to 20,000 persons. He experimented on water from a stream which contained the wastes from a woollen mill to see if the effluent could be used for dyeing purposes when very delicate shades were required. The filter was completely successful.

328. Colonel Ducat, lately one of the engineering inspectors of the Local Government Board, has patented an "aerated bacterial self-acting filter." The sewage is run through a sedimentation tank and into a screening chamber to remove all detritus, mineral and large matter, such as rags, paper, &c., whence it passes on to a filter 8 feet deep. The first 36 inches is composed of 1-inch, ½-inch, and 1¼-inch pebbles in equally deep layers. This is laid on a bed 6 inches deep of 3-inch pebbles, which acts as an aerating course. Another similar course is laid 24 inches lower, with layers of ¼-inch and ⅛-inch between; 18 inches lower is still

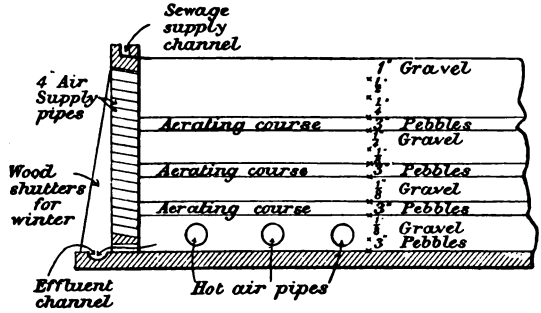


Fig 153.—Aerated bacterial filter.

another course, between which is ⅙-inch pebbles; the remaining 18 inches is similar to the last. At the bottom of the filter 9-inch pipes are laid, which in winter convey the warmed air to the outside walls and bed. Fig. 153 shows a section of the filter. In summer the outside walls are open to the air, and to every square foot of wall there are about 4 to 5¼-inch diameter pipes sloping downwards and through the wall, which allow the air to come into contact with the filtering material and pass through the aerating layers into the centre of the bed. In the winter wooden shutters are provided so that only warm air may get to the bed. The air is heated by a stove, which is placed in the centre and below the filter. The effluent runs out at the foot of the walls, and is conveyed, if necessary, for further purification to filter beds. The system is in operation at Hendon, near London. The capacity of the filter is stated to be 250 gallons per square yard per 24 hours, or about 1,000,000 gallons to the acre.

329. Since the system of bacteriology has been brought forward, several sewage works where chemical precipitation was formerly used in combination with irrigation or intermittent filtration have dispensed with the chemicals, and the tanks have been used for sedimentation purposes only. The solid matter comes down, and there it is allowed to remain; a scum is formed on the surface, and it acts, in a lesser degree perhaps, somewhat similarly to the septic tank. As may be expected, large masses of gaseous matter rise to the surface, and liberates marsh gas, just as it does in the septic tank. The effluent passes on to the land in the same manner as the chemical effluent did previously; the land is occasionally ploughed over, and made to act as a secondary bed. The discontinuance of the use of chemicals has had a better effect on the effluent, and the land appears to be none the worse.

330. At Manchester three experts were engaged to report on the best system for the treatment of the sewage from that city. Mr. W. H. Perkin, Jun., was engaged as a chemist, Mr. P. F. Frankland as the biologist, and Mr. Baldwin Latham as the engineer. They issued a very valuable and comprehensive report after visiting a number of places where different processes were in operation, and themselves experimenting biologically with beds and tanks which were erected on the existing works at Davyhulme. The report was presented to the Rivers Committee of the Corporation on October 30, 1899, and it is of such an interesting character that certain of their conclusions are given here.

331. *Trade Refuse.*—"The presence of such large proportions of trade refuse is of importance in several respects. Firstly, because the oxidisable matter in such trade refuse is in general *not putrescible*, and, therefore, of subsidiary polluting power; whilst, secondly, such trade refuse is far more difficult to remove by bacterial treatment than is the oxidisable matter in normal sewage."

"The object of purification is primarily the production of an effluent free from putrescibility, and not one in which the chemical ingredients are below some, necessarily more or less arbitrary, standard."

"The trade refuse (in the Manchester sewage) present in the sewage is incapable of inhibiting the bacterial processes."

"We are of opinion that only in very exceptional cases can trade refuse be present in ordinary town sewage in such proportion as to affect the bacterial processes of purification."

Primary and secondary beds were erected at Davyhulme, and the sewage was passed on to the beds somewhat similarly to the manner already described. The purification obtained after passing through the beds was very satisfactory—even better than the standard required by the Mersey and Irwell Joint-Committee. The effluent from the "primary" bed alone was not up to this standard, as it was in some cases "putrefactive," but the mixture of the two—that is, the effluent from the primary as "putrefactive" and "questionably putrefactive" with the non-putrefactive from the secondary bed—was found to be "non-putrefactive."

332. *Storm Water.*—They found, as others have before, that the first flush of a storm contained more oxidisable matter than ordinary sewage. This first flush, in the case of Manchester, lasts from two to four hours—depending on circumstances. This water would have to be treated as ordinary sewage.

After the first flush the flow was accelerated through the filters. They found that the effluent from the first or primary filter was sometimes satisfactory, and, with the accelerated flow, that the filters were depreciated with respect to their filtering powers.

Another important fact may be mentioned—that the sewage was of a very even character during the winter months; that although the air was at a temperature (average) of 24·8° F., the corresponding sewage temperature at the works was 55° F., and the temperature of the sewage as it issued from the filter beds was but 10° lower.

"On no occasion has any difficulty been experienced through the small layer of ice which has formed on the surface of the beds. The comparatively warm sewage at once melts the ice, and finds its way into the bed. The comparatively high temperature maintained by the sewage, even in the coldest weather, is of importance, not only in preventing the choking of the beds with ice, but also because such a temperature is necessary for the exercise by the bacteria of their functions of purification."

"The capacity of bacterial contact beds has been found to remain practically constant after they have been in operation for a period of three months, . . . in round numbers . . . about one-third of the tank capacity."

The beds may safely receive four fillings in the 24 hours, provided the sewage has undergone the preliminary subsidence and septic preparation in tanks, and that the bed is accorded about one day's rest in every week. In the event of a bed having been unduly taxed, its efficiency is only temporarily impaired, and can be restored by a few days' repose.

"Storm water may be satisfactorily dealt with by means of an accelerated bacterial treatment, which can be brought into operation as soon as the sewage is sufficiently dilute. As, however, until about two hours after the commencement of heavy rain there is no abatement in the concentration of the sewage, it will be generally necessary to provide for the storage or separate treatment of the first flow."

CHAPTER XVII.

SLUDGE DISPOSAL.

333. THE term *sludge* is intended to denote the mixture of detritus and precipitated matter which is found deposited after the passage of sewage through a tank.

If sewage is allowed to stand in a tank, matter is deposited, and when the top water is removed this matter will be found to contain about 90 to 95 per cent. of moisture, and only 10 to 5 per cent. of solid matter.

The aggregate weight of the organic and mineral solid matter may be taken to average 112·5 lbs. per cubic foot. The weight of a cubic foot of water is 62·3 lbs. Therefore, in a cubic foot of sludge the solid matter will only weigh about 5 lbs.

In 1000 parts of sewage there are close upon 998 parts of water, and only 2 parts of organic and mineral matter. The average production of sludge from a population of 1000 persons is estimated at 1 cubic yard per day. This, however, is not a constant quantity; it varies with different towns, and an approximate amount can only be arrived at by analysing the sewage.

Where the solids are deposited in tanks by the process of natural subsidence—*i.e.*, without assistance from chemicals—these figures will be fairly representative.

334. Where chemical precipitation is adopted the sludge will be increased from 30 to 40 per cent., owing to the fact that the chemical added to cause precipitation comes down with the solid matter, but where the septic tank or detritus tanks in connection with the bacterial treatment are adopted the sludge will be reduced about 85 per cent.

The great difficulty in sewage works, where precipitation by means of chemicals or subsidence is adopted, is the satisfactory and cheap disposal of the sludge.

335. In some places it is taken on to a plot of land, and there allowed to evaporate or drain through the subsoil; where this subsoil is very sandy and porous the bulk is reduced almost as efficiently as is done by the filter presses which will be described later. The matter left is then either ploughed into the land, or mixed with ashes and sold or given to farmers in the neighbourhood.

Experiments have been made on a fairly large scale to produce an incandescent gas from the solids in sewage sludge. The distillation of the gas from the sludge was attended by a reduction of bulk, and this in itself is desirable, while the revenue obtained from the gas would assist in keeping the expenditure down.

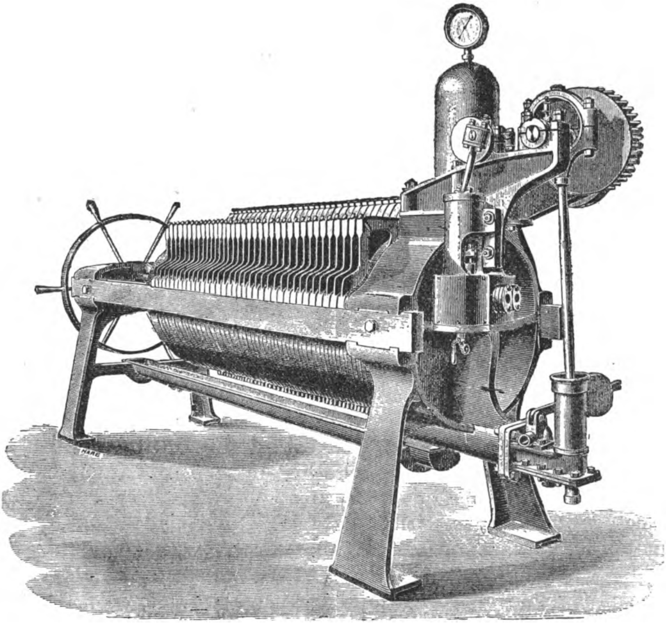


Fig. 154.—Filter press.

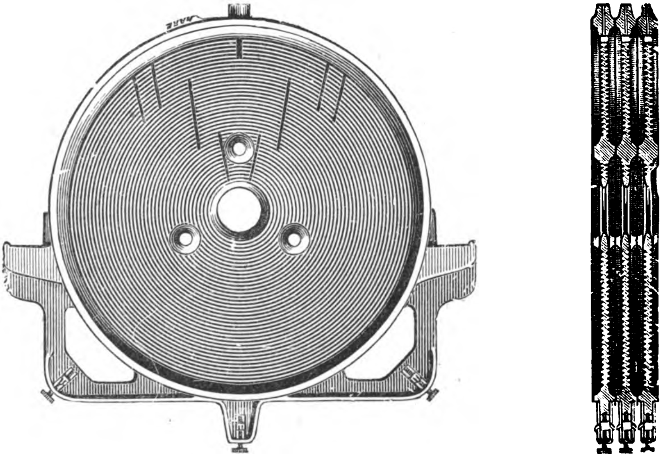


Fig. 155.—Filter press plate.

As there is a considerable amount of combustible material in certain sludges, it has at one place been poured into lagoons until it reached a solid depth of about 18 inches; when the water had evaporated and the surface was apparently dry, it was fired and continued to burn without attention.

A system of evaporation by artificial heat was adopted at another works in order to remove the large percentage of moisture, but it had to be abandoned as unsatisfactory and expensive.

336. The system that has been adopted in most places is that of pressing the moisture out of the sludge by powerful presses. These presses are made by several firms, and that shown in Fig. 154 is typical. A description of one applies equally to the others. All consist of a very strong framework, on which are placed plates which are hollowed out and ribbed concentrically or vertically, so that when two plates are put together a hollow space is enclosed. Through the centre a circular opening is made, as shown in Fig. 155. The plates are hung on to the framework by the clips at each side of the plate, and, when in position, a woven piece of fibrous matting of jute or of hemp canvas is placed between each couple of plates, the canvas covering the entire hollow space enclosed. They are pressed together by either manual labour or hydraulic, pneumatic, or mechanical power. The end plate is connected by a valve with the rams, which are generally out of sight or below the surface of the floor on which the presses are placed. The rams are cylindrical with semi-circular ends.

The sludge, after being mixed with a quantity of lime (in a liquid state) to make the sludge cohere when in the cake state, is allowed to fill the rams, and when full the supply is closed by means of a valve. Immediately compressed air is sent into the rams, which forces the sludge through the canvas and holes in each plate until it is full, the liquid pressed out of the sludge runs out from the hollow spaces of each plate, and is conveyed to the sewage well to be treated again.

The ram may be equal in size to the capacity of the press which it supplies; otherwise it may be easily determined when the spaces between all the plates are full by the quantity of water issuing from the taps at the side of the press. In the pressing room compressed-air gauges indicate the pressure of the air from the compressor. The air pressure is about 60 lbs. per square inch.

Fig. 155*a* shows a method of erecting a sludge plant.

337. The amount of lime used is equal to about 4 per cent. of the volume of the sludge. It depends on the quality of the sludge, and may be regulated by experiment.

The sludge is reduced to a cake, which may easily be handled when the plates are parted. The volume is in bulk about one-fifth the original volume—*i.e.*, 100 tons of sludge containing 90 per cent. of moisture becomes 20 tons of cake containing about 50 per cent. of moisture. Therefore about 80 per cent. of the moisture is removed by this process.

The cost of these operations vary; the lowest is about 6d. per ton of sludge or 2s. 6d. per ton of cake.

The cake is inodorous, does not appear to putrefy, and hardens on exposure to the air, but should not be allowed to become damp by rain before being disposed of to farmers, some of whom will pay a small sum in order to obtain it for manurial purposes.

Applications for the cake are, however, not numerous enough to dispose of the large quantity made, it is therefore further reduced by burning it in refuse destructors.

338. Occasionally the sludge as it comes from the tanks is mixed with the domestic refuse and burnt in a refuse destructor; a small quantity of heat is obtained which will hardly, however, give power enough to work the blast, but whatever heat is generated the extra amount of coal used in order to obtain useful work is very much decreased.

The excreta from pails is also disposed of by burning it in refuse destructors. But it is oftentimes discharged into the sewers, the refuse being emptied into a small tank nearly full of water; the water and refuse is well proportioned, and is suddenly emptied into the sewer. In some places a shoot is built in the shape of a truncated cone, the open-pointed end being turned into the sewer, the

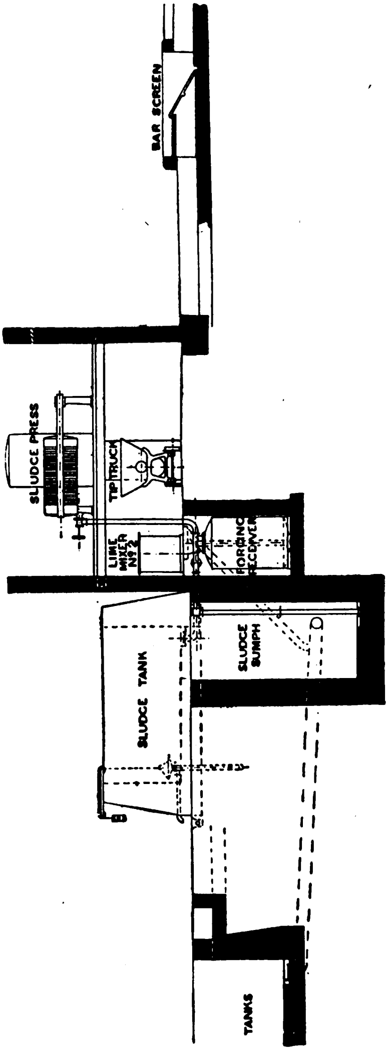


Fig. 155*a*.—Johnson's sludge plant.

contents of the pails are poured into the shoot, and water from a 3-inch hose pipe connected with the water main is played on to the refuse until it disappears.

339. At Rochdale the refuse is converted to a manure which sells at the rate of £8 per ton. The lighter and more combustible portions of the house refuse are separated by means of a screen, and used as fuel to dry the excreta from the pails, that portion of the combustible matter not required for this purpose is destroyed in a refuse destructor. The drying of the refuse from the pails leaves it in a portable state, and seems to have a good sale.

In some towns the excreta is taken to the depôt and put into a tank, the sides of which are formed with the ashes from ashpits, &c.; the liquid is absorbed, and the whole is thoroughly mixed together, and is disposed of to farmers.

340. When sewage is of a very oily, greasy, and soapy nature it is possible, by adopting a chemical process, to obtain the grease from it in commercial form. Grease has a saleable value of from £9 to £12 per ton, depending on whether it is saponifiable or not, that which is not saponifiable has a value of only about £2 to £3 per ton.

At woolcombing establishments it is now the custom to treat the washing suds with hydro-sulphuric acid which, when added to water containing grease, "cracks" the liquid and brings the grease to the surface, the water is then filtered through canvas, and the grease remains behind in sufficient quantity to pay for the treatment; it may be possible, indeed, to obtain a small profit.

A similar method of treating the sewage and trade refuse is in operation, with a likelihood of large extension, at Grimonpoint, where tanks have been erected to receive the sewage, refuse, &c., from the towns of Roubaix and Tourcoing, in the Département du Nord. The population of these towns is about 230,000, the chief industry is woolcombing, some of the largest mills in the world being situated in this neighbourhood. The quantity of trade refuse is consequently very large and equal to about 20,000,000 gallons per day, the whole of which flows into a small beck.

The tanks are in sets of six, each set being worked independently, and each tank individually being set the same amount of work in the depositing of the sludge, the result is that the sludge is of a greater density than is usually found in England, and contains only about 83 per cent. of water.

The acid, which is made on the works, is used in the proportion of 80 grains of acid to 1 gallon of sewage. The sludge is pumped into a long sloping cylinder about 3 feet diameter, benzine is then pumped into the lower end of the cylinder in the proportion of two of benzine to one of sludge, the benzine absorbs the grease, and the mixture, which rises to the surface, is floated into a still, where the benzine is evaporated and distilled for use again, the grease remaining behind.

The sludge after treatment is pressed in the ordinary sludge press and sold as a fertiliser, it being thought highly of as the cake is impregnated with a trace of benzine, which is said to act as a vermin killer.

The patentee is M. Jules Delattre, woolcomber, of Dorignies. The process would only be profitable in England under certain conditions—(1) The sludge would have to yield at least 5 per cent. of grease, which should have a marketable value of £9 per ton; and (2) the sludge cake should have a sale at the rate of about 10s. per ton. The price of sulphuric acid (B.O.V.) in England is about 35s. per ton.

CHAPTER XVIII.

CONSTRUCTION, MATERIALS, AND CLEANSING OF SEWERS.

341. It is not proposed to enlarge on either of these subjects to any great extent. Several modes of construction are mentioned in detail which may be common knowledge to an engineer of experience, but to the student they may be useful and cause him to closely watch and examine the different constructions that may come within his view. There is nothing from a practical standpoint more important to the student than the taking of sketches of even the simplest of constructions of any works he may have the opportunity of examining. There is always something to be learned; every engineer and contractor has his own methods of carrying out his works.

342. The preliminary step in the construction of the sewer is the setting out the line and levels. To those who have been accustomed to take sections of roads or fields, it is sometimes perplexing, unless great care is exercised, when the proceedings have to be reversed, as mistakes are often made by leaving the boning laths or sight rails with a fall in the wrong direction. Bench marks on serviceable stakes, in positions not likely to be touched, should be set out frequently along the line of the sewer, each stake having its level distinctly marked upon it.

The boning rod should, if possible, be retained at one length throughout the line of the sewer; if it is to be altered, the material of which the first one is made should be cut or removed from the works. Generally the length is about 4 feet longer than the average depth of the sewer below the surface of the roadway or field. At its foot is fixed a shaped piece of iron to fit into the invert of the pipe and socket.

Two stakes are placed, one on each side of the trench, and a sight rail or cross bar is levelled and nailed firmly to the stakes at such a height that, when the boning rod is vertically placed with its cross-piece level with that of the sight rail, its foot will give the exact level of the invert of the pipes to be laid.

The next sight rail is fixed on the line of the trench about 100 yards distant, and is fixed similarly to the one already described; but it will be higher than the original rail in order to give the fall the sewer requires. Another sight rail should be fixed between these, and the three should be exactly lineable; they should remain so that, if either or any of them gave way or through an accident should have been knocked down and inaccurately set up again, it could easily and immediately be detected.

343. The trench having been set out, a rough line is given to the navvies, which is an inch or so within the accurate line; they work at the trench, excavating the material, until it is about 3 feet deep. Immediately following the navvies is the timberman's gang; the sides of the trench are now accurately struck out with a line, and they pare away (using a plumb-bob and line) the sides until they are truly vertical to receive the 3-feet boards, 1 inch or more in thickness, which are to be sufficient to support the sides before any greater depth is attempted; the walings are now placed temporarily in position, being supported by props from the bottom of the trench, the poling boards are then put between the walings and the side of the trench and supported in their correct position by nails. The struts are cut to size before the trench is commenced, one less in length than the permanent strut is driven between the walings, and the permanent one immediately follows it, the temporary one falling out, the nails are removed, and this portion of the trench is ready for the navvies to excavate another depth; the process is then repeated. Struts and walings are always placed vertically over each other. Trenches, 20 feet deep, have thus been made through indifferent soil, and every piece of timber drawn at completion practically without damage. The drawing of the timber is made after the filling in has been brought to the level of the waling, the struts are knocked out and the walings removed, the trench is filled up again until there is left just sufficient room to lever the poling boards out.

344. It will be found necessary, in treacherous ground of other than quicksands, to leave in, if not the whole of the timber, the walings and struts that have been used in supporting the sides of the trench, especially if buildings are close to the line of the sewer, and if the subsoil be of loose clay which runs in and out of the trench, and which is underlain by sand, gravel, and water.

In the case of a subsoil of running sand or quicksand—*i.e.*, a fine sand to which water has obtained access—this mode of timbering would not prove successful; the trench is then made wider at the surface in order to allow for thicker and stronger poling boards. If the sand be at a depth of 10 or 12 feet below the surface and the soil above be firm and stable, the trench would have to be about 12 inches wider than for one through a comparatively solid subsoil. This would then allow for an inner setting to be placed at that depth.

In this case the poling boards are about 3 or 4 inches in thickness, and are tongued and grooved, the tongues being made of iron or hard wood. Walings are fixed in position, and the poling boards placed about an inch behind them, and kept this distance back by wedges, so that they may be the more easily driven further down as the trench is excavated. Thus the sand is prevented from running into the trench. Walings are placed with a space of 3 feet between them, and as the poling boards go down others follow on top of them. It will be seen that here the timber would have to be left in to a very large extent. Part of it might be removed, but for the safety of the sewer and road, surrounding walls or buildings, it is necessary that it should remain. The removal of any timber should be entrusted only to capable men, as an inexperienced man might easily let the sides in by an injudicious removal of certain pieces, and render the trench dangerous to those working in it.

345. The method just described is favoured by some for ordinary trenches, the poling boards not having the tongue or groove. It is not economical, as the loss of timber is considerable and the labour more costly.

346. Should a sewer be at a greater depth than 20 feet and the ground be solid, it may be found to be less expensive to tunnel. A sewer which is to be built in tunnel requires carefully setting out. The centre line is first laid down on the surface, and a shaft is sunk on the line, from which the work of constructing the tunnel is carried out. Two points are defined permanently, one on each side of the shaft, each of which is placed in a convenient position, and is truly and vertically under the line as marked out on the surface. Heavy plumb-bobs are dropped to the foot of the shaft from three points, and if the shaft be deep the bobs are allowed to hang in buckets of water in order to get the lines perfectly steady. These vertical lines on each side of the shaft are used for sighting the centre line in the heading of the tunnel. Points are also fixed in the bottom of the shaft which are also vertically under those at the top, but these are liable to be displaced, and should be occasionally checked. The centre line may also be marked out by a theodolite.

The longer the shaft in the direction of the tunnel the greater the accuracy in the setting out of the line in the heading or drift; *e.g.*, suppose the length between two shafts be 400 feet, if one of the vertical lines dropped from the top of the shaft be $\frac{1}{8}$ inch out of truth and the length of shaft be 6 feet, the difference would be at the centre equal to 4 inches, and if the point at the second shaft also similarly varied, the difference at the centre would be 8 inches. If the length of the shaft be doubled, the differences would be just half of those given.

Should there be a curve or angle in the tunnel, it would be set out below the surface somewhat similarly to the method adopted above ground, a theodolite being used to give the necessary deviation angles.

347. The timbering of a tunnel must (as with trenches) always be

adapted to the soil which it is to support. As much of the timber is to be left in the tunnel work, it is desirable to give adequate support, with economy in material, as, once it is used, the value, even if taken out again, is greatly depreciated. The sewer may be of such dimensions that it may be constructed simultaneously with the tunnel, the sewer being strong enough in itself to withstand the pressure of the earth above it, and its dimensions being such that it may be used for the conveyance of the excavated material. For such a case the arched method is a very economical one, as only one piece of timber is left in together with the thin sheeting.

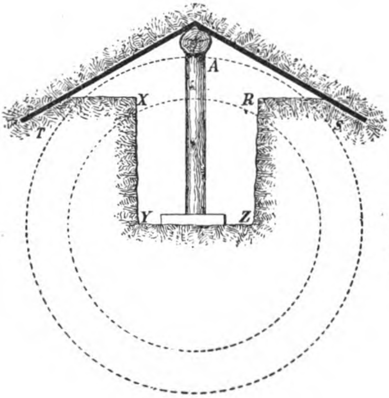


Fig. 156.

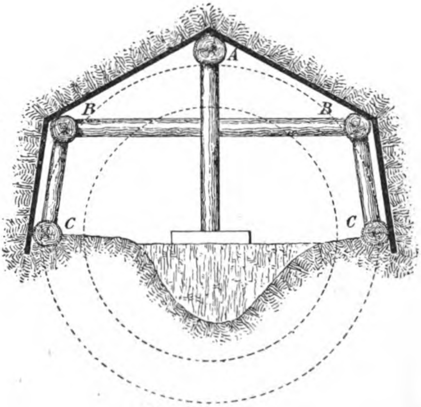


Fig. 157.

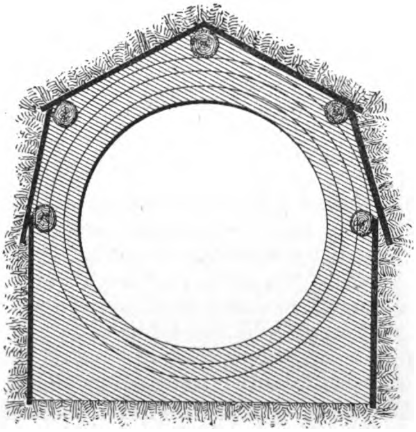


Fig. 158.

The accompanying sketches (Figs. 156, 157) show the procedure. A heading X Y Z R, is made just large enough for a man to get in and work, 3 feet 6 inches high and 2 feet wide for a length of about 7 to 9 feet, and the larch pole A is inserted above the brickwork intended to be built in, and supported by upright timbers at each end; or, if the sewer is built up to the tunnel, one end would be supported by the brickwork; the arch of the tunnel is then cut, and poling boards put in position, as shown by A T and A S, these being temporarily supported by the earth which has been thrown into the heading. The larch poles B are then placed in position; part of the earth removed until the sides B C are open to put these poling boards in. The poles C are then placed, and the whole of the earth is removed down to the invert. The sides from C downwards are poled and adequately supported laterally until the brickwork forming the foundation of the sewer is built up. The brickwork is taken up to the springing, and supports the sides B in such a manner that the poles C may be removed as soon as the work is set. The arch is then built, and the poles B may also be removed, as the polings B C and A B are supported by the arch. Care must be taken that the timber rests equally on the brickwork if the poles are removed.

When the sewer is of small dimensions and composed of pipes the tunnel should be made from end to end, of such a size that the men may conveniently work in it. Figs. 159 and 160 show constructions for pipe sewers.

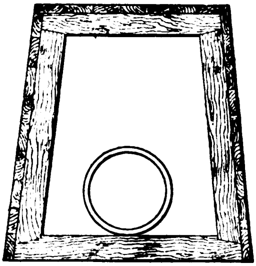


Fig. 159.

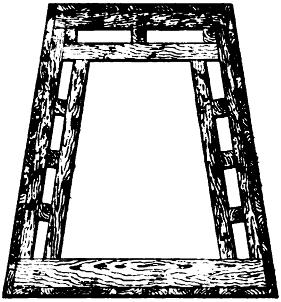


Fig. 160.

348. If the earth is of such a character as to occasion a fear of danger on account of it containing water, it may be desirable to erect a pump in the immediate vicinity, and sink a shaft several feet below the proposed invert of the sewer; then pump the water for a week or two before commencing work. The water may leave the earth in such a condition as may easily be worked with speed and confidence. The timbering, however, should be strong enough to provide for emergencies.

349. It is necessary, on account of the unstable character of some portion of the subsoil, to alter and amend the foundation of a sewer. The author had a case where a large brick circular sewer

sank 6 inches for a length of about 15 feet. The sewer was taken out, and excavated to a depth of 12 inches below the level of the sewer on each side of the length that had settled; this was filled up with concrete and allowed to set; afterwards the sewer was rebuilt. It settled a second time. It was again pulled out, and, in place of the concrete, the trench was lengthened, and baulks of timber laid longitudinally. These were planked over with 3-inch boards; concrete was then laid on the planking, and the sewer built up the third time. This proved an effectual remedy, as the sewer remained perfect in line.

350. Should there be a large amount of subsoil water in the trench, it is advisable to lay a subsoil drain below the foundation of the sewer, into which the water may run and thus keep the trench dry for the construction of the sewer. The drain should have open joints, but not so as to allow sand to obtain entrance. A quicksand subsoil is of such a nature that it will find its way into these drains almost as easily as water will do; a chain is therefore sometimes left in the pipe, which can be dragged backwards and forwards in order that the water may have a free flow. It is not desirable for these drains to remain open after the sewer has been built, especially in a subsoil of quicksand, as, if there is a free outlet, or if the drain be continued under a long length of the sewer, they drain away the sand with the water and endanger the foundations. If, however, the subsoil is an open gravel without sand, they may be useful in keeping the sewer free from subsoil water.

351. Should sewers pass through a subsoil of very unstable character, the material originally specified for the pipes may prove unsuitable, and occasionally iron pipes are substituted, it having been found that the nature of the earth would cause earthenware pipes to subside. Oftentimes they will on examination be found broken.

Trenches through clay and marl are treacherous, especially in wet weather, for although at first sight the trench seems to be self-supporting, it gives quite a wrong impression; such an excavation requires almost as much timbering as one through a firm soil.

Houses and buildings near the line of a trench may require to be propped until the trench is filled again and restored to its original state.

To illustrate the pressure exerted by wet sand, the author saw a 9-inch square strut, ½ inch deep in a 12-in. × 6-in. waling, and in a gas tank excavation a similar strut was forced through the waling.

352. It is necessary at times to timber the bottom of a trench in order to prevent the escape of the material from the sides, which might otherwise be the cause of a collapse.

353. Brick sewers with small inverts should have the base

extended over a large surface in order to distribute the weight of the earth over the sewer in a superior manner than would be the case if there were merely two courses of brickwork following the curve; where inverts have but a small radius it is difficult to obtain bricks suitably radiated, and to lay them accurately even if obtainable. There are made for this purpose earthenware invert blocks, which serve to satisfy both these objects. Fig. 161 shows the cross and longitudinal sections of such a block; the latter illustrates the joint.

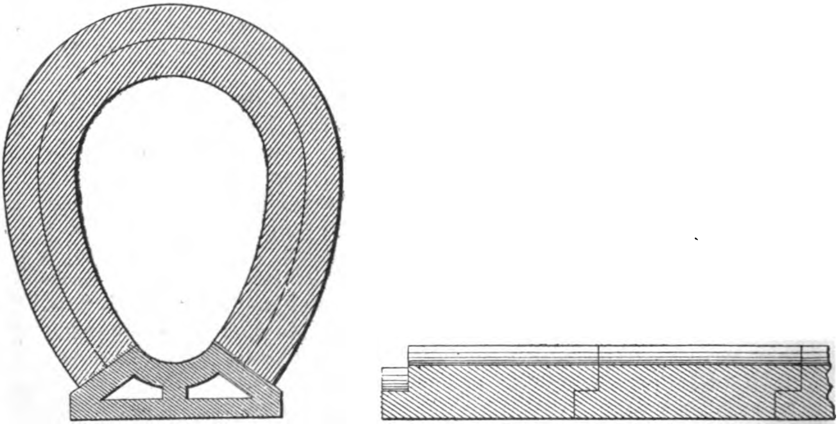

Longitudinal Section.

Fig. 161.—Section of brick sewer.

354. The material on which the pipes are bedded should be the finest possible from the excavations—fine cinders or ashes serve the purpose where the bed is hard and unyielding; a cushion is formed by this means which prevents any breakage of a pipe due to the weight of the filled-in material. The bottom of the trench in a firm but yielding foundation should be so excavated that the whole of the pipe rests solid; in order to obtain this a small hollow has to be made in the bottom of the trench, into which the socket of the pipe fits (see Fig. 162). The pipe having been laid truly in

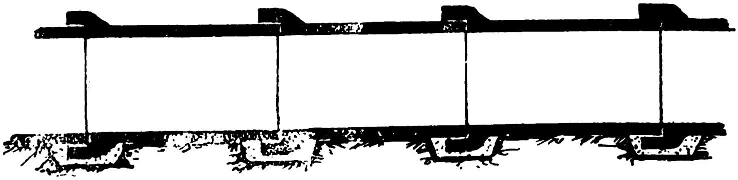


Fig. 162.—Mode of bedding pipes.

level and line, and jointed with cement, the space between the pipe and the sides of the trench is filled in with selected fine material, and wedged in tightly by spades or tools. In some cases this fine stuff is filled into the trench to a height of 12 inches over the pipes. The filling in of the trench is then continued in layers of 9 inches, each layer being well punned in with a 7-lb. punner.

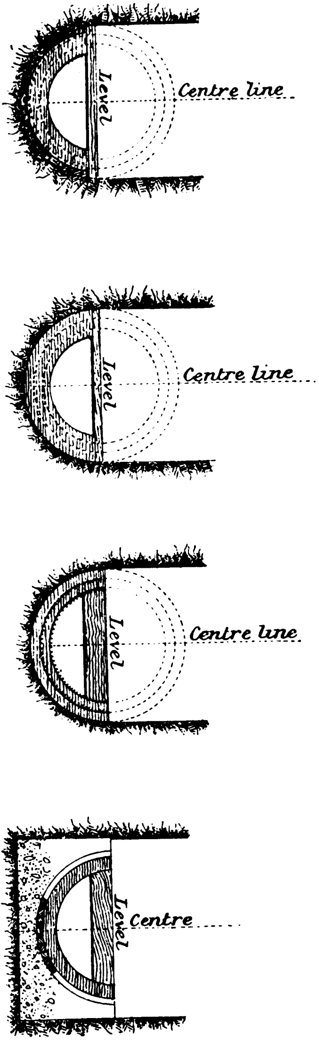
355. To test whether a length of pipes is water-tight, which should be a *sine quâ non*, each end of the sewer is blocked up, as are all junctions. The sewer is then filled with water, and allowed to stand with a head of from 3 feet to 6 feet. Should the water after standing for some time become lower in level, there is a leakage somewhere which requires stopping. To make the ends water-tight an arrangement may be obtained which consists of two discs of wood a little less in diameter than the inside of the pipe; between them is india-rubber tubing, which fits to the face of the pipe; the two discs are brought nearer together by means of a screw; this forces out the rubber against the pipe, and effectually prevents any water from passing. Another method is to place an india-rubber bag in the pipe, which is about a foot long. It is fitted with a valve and tube, and air is pumped through the valve until it is firmly in position.

356. In laying the pipes the joints should be wiped inside, as, in tapping the pipe into its final position the cement from the joint is pushed into the pipe and, if allowed to set, would form an obstruction to the future flow of sewage. Usually a half-disc is formed of wood about half an inch less in diameter than the pipe, a strip of india-rubber is fastened on to the outer edge, which fits the half-pipe, and a handle about 3 feet long is attached, and this forms what is known as a *badger;* it is left in the pipe and drawn forward when the next pipe is in position and jointed; it cleans first the bottom half of the joint; and when pushed back, turned, and again drawn forward, it removes the cement from the top half.

An examination of the sewer should be made when completed, as occasionally clay, tools, shovels, &c., are left in, and would form a serious obstruction. In larger sewers such articles as centres are frequently left in, and sometimes a barrow or mounds of cement will be found.

357. The construction of a brick sewer requires the employment of men who have been accustomed to the work. The trench is made down to the springing of the sewer in a similar manner to that described in Art. 343 for pipe sewers, but below this a roughly-made frame is used for a guide, the frame being about 3 or 4 inches less than the required size, as shown in Fig. 163. Following these are more skilled men, who have a frame which gives the exact form of bed on which the brickwork is laid, as shown by Fig. 164; this frame is placed in position about 20 feet ahead of the brickwork, the men cut and pare at the trench, using line and rule, in order to

obtain a true bed for the outside of the brickwork. The bricklayers immediately turn into the excavation and have as a guide another frame, the exact width of which is that of one ring of the brickwork (Fig. 165); on the inner edge of this frame nails are driven in showing the exact position of every course. For the succeeding rings of brickwork other frames are used, and similarly marked.



Excavators rough frame 163.

Excavator finishing frame. 164.

Bricklayers frame for first and second rims 165.

Method of forming concrete bed 166.

Figs. 163-166.—Constructing a brick sewer.

358. When a concrete foundation is to be put in prior to the brickwork, two strong frames are made, the outside edge of which is 3 inches less in radius than the outside edge of the brickwork. Laths are then made radiated on the edges, 3 inches deep, and concrete is well punned into the bottom of the trench (Fig. 166); three laths are placed longitudinally under the outer edge of the frame and the concrete rammed underneath until the laths are accurately in position; another lath is added and the concrete rammed again, and so on, until the laths and concrete have been put into the springing on each side; each side must be concreted regularly and equally. When the framing and laths are removed after the concrete is set, the foundation is ready for the bricklayers.

359. The construction of inverted syphons across rivers are frequently necessary. In some instances it may be policy to construct a large culvert under the bed of the river, and inside it place the pipes

which are to take the sewage; then gas, water, or electric mains may also be run through—thus the cost might be distributed. The pipes in such a construction could easily be examined, altered, and increased in size at any future time at very little cost.

The culvert or sewer syphon must be placed below the bed and sufficiently protected from floods by piling and cross timbering, which must not affect the flow. Similar methods are adopted in piling and cross timbering in rivers as are carried out in the laying down of an outfall sewer through the sand, &c., forming the shore, into the sea.

The actual cost of laying the pipes is comparatively small; the expense is in the forming of a coffer dam which will enable the men to work without risk.

360. In the case of a crossing of a river, if concrete is to be used round the pipe, as shown in Fig. 167, there would have to be sheeting parallel with the sewer in order to retain it in its position. The piles and sheeting must also be kept below the bed of the river. It then becomes necessary to construct two dams, as shown, each about 4 feet, outside the line of the sheeting; these would be driven down far enough to withstand the pressure of a flooding of water in the river. The inner piles and sheeting could then be driven in with ample room for working; the space between it would also be comparatively free from water in certain river beds, and the excavation could be the more easily carried on than if the inner sets of piles had been lengthened to the same height as the outer sets. There is very much less waste of timber, as the major portion of the outer timber could be removed bodily and be used again for this or for some other purpose. The timber would be less shaken by the driving, and the difficulty of cutting the timber at

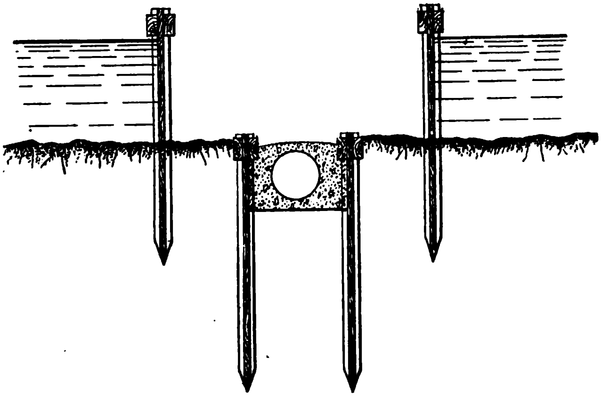
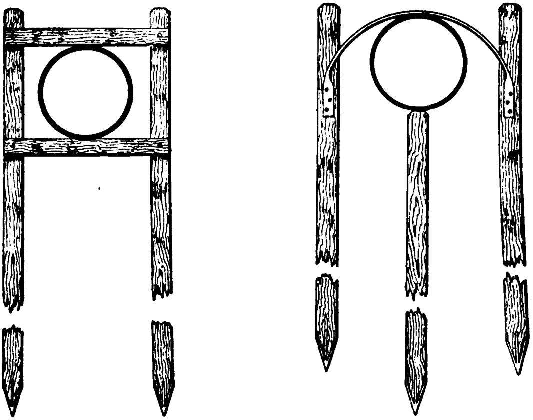


Fig. 167.—Carrying pipes across a river.

the bed of the river would be removed. When the sheeting piles do not prevent the water from entering the trench, an inner setting may be put in about a foot from the outer sheeting, and the intervening space filled in with clay puddle. This is usually effective. Figs. 168 and 169 show other methods which have been adopted in anchoring down pipes in river beds and sea shores. Fig. 169 shows how the piles on the centre line support the pipe, one being placed at each end of every pipe; the other piles are placed parallel and with the same frequency on each side; a strong iron strap is taken over the pipe and bolted at each end to the side piles. Fig. 168 shows the centre pile abandoned, and in its place a cross-piece bearing the pipe and bolted with strong bolts to the side piles, and instead of the iron strap a cross-piece is placed across the top of pipe and similarly bolted to the side piles.



Figs. 168 and 169.—Carrying pipes across a river.

361. **Drain Testing and Cleaning.**—After a system of drainage has been made in connection with houses it is usual to test whether the drains are air-tight, and are not defective in any joint which would otherwise allow gases to penetrate into the breathing atmosphere. Should a drain be suspected, or should complaints have been made that it emits a smell of sewer gas, it is also probable it will also emit other pungent smells should they be placed in the drain.

362. Various appliances have been designed which have this object in view :—(1) One apparatus is in the form of a wooden ball (Fig. 170); a groove is run round the diameter, into which a ring of brass D is placed, which forms a hinge for a catch B D; in the centre of the ball is a spring F, placed vertically to the grooved

diameter. On the opposite side to the catch B D is a lever G, hinged at H. Two small staples are fastened into the top of the ball, which allow for the insertion of a hollow thin glass-sealed grenade containing a powerful smelling chemical—*e.g.*, peppermint, &c. When ready for testing the drain, the lever is forced over the spring until the end J just catches in the clip B D through the slot C, and the grenade is fixed through the staples A. The ball is then placed in the W.C. or gully trap, and a flush of water takes it into the drain. By pulling the cord which is attached to the clip B D the lever is released, and springs back with such force as to break the grenade and discharge the odour, which will penetrate through any defective joint, and make itself apparent in a few minutes.

363. The smoke test is applied in a variety of ways. (*a*) Small rockets about 12 inches long are filled with paper saturated in a chemical, which, when fired, makes it smoke and not burn into a blaze. Gunpowder to a small extent is also included in the composition. The rocket is placed in the drain, the latter covered up, and the end is set fire to in the usual manner, the paper smoulders until it reaches the powder, which forces a large volume of smoke forward into the drain; this also penetrates through any defect, and issues into the open with a peculiar odour. All openings, such as ventilators, must, of course, be closed before the rocket is placed in the drain. The rocket will sometimes be found about a yard from its original position after the discharge has occurred. (*b*) Prepared paper is obtained, which will smoulder and cause a large volume of smoke. This is placed in a small iron tank, at the side of which is an india-rubber tube, the other end of which is placed in the drain. At the other side of the covered tank containing the smoking paper is another tube attached to a blower, which may take the form of bellows or fan, and which will be worked by hand; the air is driven into the bucket, and forces the smoke into the drain through a stopper. Fig. 171 gives an illustration of this process,

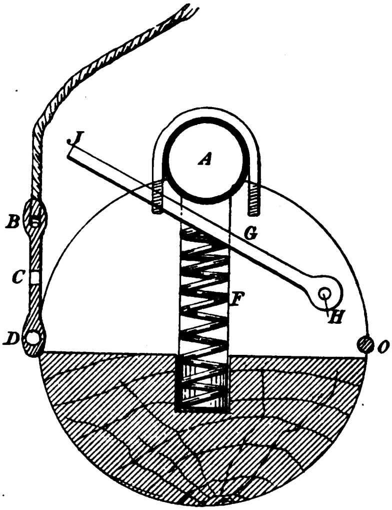


Fig. 170.—Drain-testing apparatus.

the space G being filled with prepared paper, engine waste, &c., or honeycomb cartridges, which are made by Messrs. Banner, whose apparatus is here shown. The drains are perhaps more effectively tested by the smoke test than by the chemical grenades, the effects of which must be over only a small area.

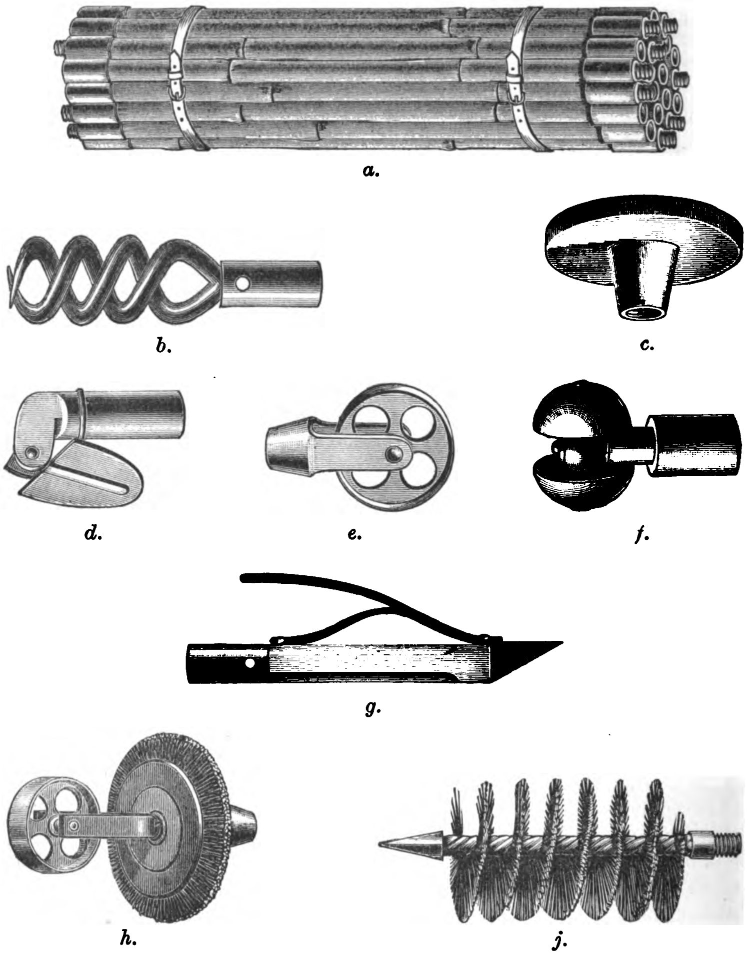


Fig. 172.—Ham, Baker & Co.'s drain-cleaning machinery.

364. The clearing away of obstructions in a small sewer is accomplished by means of different instruments, each of which

may be screwed, as required, on to the end of a malacca-cane rod. Another rod may be screwed to this, and it may be lengthened to any extent, as other rods may be added until the instrument reaches the obstruction. Figs. 172, *a* to *j*, show the usual fittings; the usefulness of each will be easily seen.

The drain may be thoroughly cleaned for a length of about 150 to 200 feet on each side of any given point with these appliances; thus the breaking of the pipes and cost of excavating, down to the place where the obstruction may be, is obviated.

CHAPTER XIX.

REFUSE DISPOSAL.

365. THE science of Sanitary Engineering is of such scope that the subjects which it deals with may be classed into sections, several of which have already been dealt with. The most important of the subjects which do not come within this scope is scavenging.

Scavenging includes the cleansing of streets, the collection of street and house refuse, and its subsequent disposal.

The Public Health Act, 1875, provides that every Local Authority shall undertake the removal of house refuse from premises, and if, without reasonable excuse, the Authority neglects to cleanse the ashpit within seven days after receiving notice in writing from an occupier of any house, certain penalties may be imposed. The Local Authority is also empowered to provide fit buildings and places for the deposit of such collected refuse.

There is a vagueness about the words "house refuse," and it is difficult to give a meaning to them. It includes, from an examination made at a sanitary depôt, ashes, tins, broken earthenware, pots, glasses, paper, rags, bottles, straw, &c.

Ashes are a variable quantity. In some towns there would be a marked percentage of cinders, while in others it would be mostly dust, on account of the carefulness of the inhabitants. Tins until recent years were sometimes set aside and burnt in order to obtain the solder, but they are now in many cases blocked into shape; as a result, the amount of solder obtained is so small that it is not considered worth the trouble of extraction. The tin itself is of little value, but in some towns it is sold, and used in the making of copperas. Earthenware materials hardly pay for the sorting, &c.

Ashes as a combustible refuse must be a depreciable quantity in proportion as the use of gas stoves and electricity becomes more common, and as people recognise the waste that takes place at their own hearths.

The method of collecting house refuse is by making a house-to-house call, the refuse being kept temporarily in bins, as described in Art. 117, and carts are sent round once a week to remove it to some convenient storage place, the capacity of the bin being about 3 cubic feet.

The method of storing the refuse in some towns is in an ashpit of large dimensions, about 12 cubic feet per house, or 21 cubic feet for two houses. This is removed only once a month. In other towns the time that elapsed between each call was two or three months. But this order has been changed, and the more sanitary system has been adopted in most districts of not allowing more than one week's refuse to be stored.

The large ashpits should only be allowed in large establishments, such as hotels, schools, hospitals, &c., and these should also be removed once a week at least, twice a week if possible—that is, before the vegetable and organic matter has begun to decompose.

366. The tub or receptacle for the refuse should be impervious, sheltered from rain and wind, removable without inconveniencing the household, and secluded from general observation.

The carts employed for the removal of the refuse should be specially constructed with a view to prevent the paper and dust being blown about the streets in high winds. The refuse is either deposited on to tips, sent away by rail to farms, shipped, and deposited at sea, or burnt in destructors.

The method of shipping it and discharging it into the sea is perhaps a convenient one at seaports and other places on the coast, but it must happen that the light and buoyant material will eventually find its way on to the coast line.

367. In some cases there is an elaborate system of sorting of the material in the refuse, and perhaps the most complete method was that adopted by the Refuse Disposal Company at Chelsea (now extinct). This method was favourably reported upon by Mr. Harpur, the Borough Engineer of Cardiff, who recommended its adoption for that town.

The system appeared to be very effective in removing all particles of dust at every stage of the sorting by a series of exhaust fans which conveyed them into furnaces, so that the annoyance to sorters was removed and the dangerous constituents destroyed.

The refuse was tipped into a cylinder screen revolving on its longitudinal axis, the openings in this cylinder allowing all articles of a size less than-10 inches by 2½ inches to pass through to a second cylindrical screen revolving beyond the first, which allowed those articles of a less size than 1¼ inches to pass through to another cylindrical screen further away which was of a ⅜-inch mesh.

By the first process the paper, rags, straw, bags, &c., were sorted for papermaking. Tin cans, bottles, and pottery ware were removed to different heaps, and boxes were collected for burning, all being separated by hand, the screen being composed of hardwood bars in order that bottles could not be broken. The material left in the screen was moved forward by a coarse wooden worm.

The second screen, which was also fitted with a wooden worm, met a strong blast of air which drew all paper and light refuse to a chamber or box. The material not affected by this draught of air fell from the screen on to a continuously revolving iron table. The refuse was here sorted again, and each material removed to its respective bin, the products being bones, large coal, coke, cinders, metals, glass, and crockery.

The refuse in the third screen and the residue which issued from it were also sorted—one portion being dust and another cinders and breeze. One was mixed with clay, from which bricks were formed; the other provided fuel for the furnaces.

A portion of the site was set apart for the making of brown paper and cardboard, which would take the articles suited to its manufacture. The glass, crockery, metals, &c., were disposed of at remunerative rates.

368. In Paris a small army of men were some time ago employed in picking out the tins from house and other refuse. These were sent to a stamping mill, where they were converted into toys.

They are also useful in the manufacture of copperas and of metallic oxide. The tin, at Bradford, is sold at the rate of 4s. per ton.

Broken crockery is saleable, and glass has a marketable value of £2 per ton. In Salford 208,020 mineral water bottles and 15,722 other bottles in one year were taken from the ashpit refuse, and about 97 tons of broken glass were picked up from the streets during the same period. The revenue brought in by such glass was about £150 per annum. The Manchester Corporation receive £30 per annum for allowing persons to pick out the bottles, the broken glass being further broken up and mixed with the mortar, which is claimed to be better for such addition. In other cases it goes with the refuse to the furnace, and assists in fusing the clinker.

Cast iron is readily bought at about £2 per ton. At Bradford this brings in an income of £150 per annum.

It has been said that paper is made from the rags, bags, old dresses, waste paper, &c. This material should always be sterilised before conversion, otherwise there would be risk of some infectious disease being inadvertently spread.

There is still another class of refuse that is taken by local authorities—the refuse from grocers, greengrocers, fish dealers, butchers, and other tradesmen.

Vegetable matter decomposes quickly, and it is desirable that this should be promptly destroyed.

Fish may be converted into manure of great commercial value, and it is so manufactured at Rochdale and Bradford. At the latter town it is readily sold at the rate of £3 per ton. The authorities deal with fish refuse to the extent of from 600 to 700 tons per annum, which by treatment is reduced to 25 per cent. of its original bulk. Butchers' offal may, after treatment, be made into a manure, as also will leather, both of which will contain from 7 to 11 per cent. of ammonia. The fish manure contains about the same proportion of ammonia, but, in addition, there is phosphoric acid and lime (about 1·5 to 2 per cent.), which are also fertilisers of considerable value.

369. House refuse will contain a variable proportion of moisture. In some towns it may be as low as 15 per cent., but the average is about 40 per cent. If sludge or excreta be mixed with it, the amount of moisture will probably be increased to 75 and 80 per cent.

It has been the custom in many towns to dispose of this class of material in old quarries, ravines, disused brickfields, but the system is pernicious, as the accumulations of putrescent matter have been the cause of a nuisance to the neighbourhood, and objectionable smells must, and do, pervade the atmosphere.

These facts have been recognised by local authorities, and they have applied themselves to the disposal of the refuse in some other direction—particularly the destruction of refuse by fire.

370. It is a quarter of a century since the destructor was acknowledged as a means for the disposal of refuse. Mr. Alfred Fryer, in 1875, patented and introduced a furnace which he called a "Destructor," a name which is even now given to these furnaces, although inapplicable, as it is well known that no article can be destroyed in the strict sense of the term, but it may be changed or reduced to simpler forms.

The destructor was to receive in a cell all possible articles contained in the refuse from domestic and other sources. A part of this cell was formed with firebars, on to which the refuse was brought. The material having been ignited, the furnace was kept supplied with refuse, and the clinker formed by the non-combustible material was removed. As will be seen from the description (Art. 365) of house and tradesmen's refuse there is always some proportion of combustible material, and this was taken advantage of in burning and reducing the offensive matter in the refuse.

The destructor has been very much improved in design since Fryer's furnace was inaugurated, as during the time they were in operation serious complaints were made about the gases which issued from the chimney shafts of various installations. At that time the heat obtained from the furnace was not greater than 800° F., and the refuse, lying on the incline at the rear of the cell, gave off noxious fumes, which were generated by the heat obtained by close proximity to the furnace. These fumes had direct access to the flue with the gases from the furnace, and as the latter were not at that degree of heat that would destroy their noxious character, they therefore issued from the chimney into the atmosphere. To remedy this Mr. Charles Jones placed a fume cremator in the flue, by which all gases passing to the chimney were raised in temperature to 2000° F. The cremator was in the form of a coke furnace, and was very effective. The expense of keeping up a coke fire has been against its adoption, and other means have now been devised to attain the same purpose.

371. A refuse destructor must be in such a form that it consumes or reduces all putrescible and organic matter, and the gases ensuing from such reduction must be innocuous, sterilised, and without odour. Therefore the use of such a furnace would appear to be an admission of the weakness of design of that destructor to which it may be attached. The dust should not escape from the chimney, but be retained in such a position as will allow of its easy recovery and removal.

No gases should be allowed to enter the chimney shaft without being subjected to a temperature of at least 1300° F.

The furnace should be capable of obtaining and retaining a good hot and glowing fire from the refuse without the addition of fuel of any description, and the clinker should be hard, vitreous, inodorous, and sterile, and composed of non-combustible matter only.

372. It is difficult to give any definite proportion of combustible or heat-giving material in an average sample of refuse; roughly speaking, the amount may be taken as from 20 to 40 per cent., the incombustible material may be estimated at about 30 to 45 per cent., and the remainder would be moisture.

Inhabitants of certain districts and towns are very much more economical in their domestic arrangements than is suggested by this estimate, being careful that nothing but absolute ashes shall go to the ash-bin, and anything that is combustible shall be burnt in the grate before it is thrown away. In such a district the percentage of non-combustible material will be relatively high.

In certain other districts the refuse from houses and workshops has a high percentage of combustible articles and material. In the majority of towns the amount of inflammable material is in such quantities that with either steam or air blast the temperature of the gases may, with adequate and careful stoking and an efficient draught, be kept at 1500° F., and will often reach 2000° F.

This temperature is not necessary for the combustion and oxidation of the gases, one of 1300° F. will be quite sufficient for such a purpose. The following are the gases which will issue in some degree of intensity from the burning of refuse, and against each of them is placed the temperature at which oxidation occurs:—

Name of Gas.	Temperature of Oxidation.
Olefiant gas,	932° Fah.
Hydrogen, H_2,	932° ,,
Marsh gas, CH_4,	1010° ,,
Carbonic oxide, CO,	1112° ,,

Carbon (C_2), which is a solid, begins to oxidise at 1076° F.

But when heat is to be used for some other purpose than the breaking up of the gases and refuse—*e.g.*, in the evaporation of water—it is then advisable to obtain as high a temperature as possible.

373. It is known that 1 lb. of carbon requires for its perfect combustion about 12 lbs. of air, but in practice more air must be supplied to effect complete combustion—this quantity depending on the nature of the draught. When a chimney is used, 24 lbs. of air are required per lb. of carbon. But when artificial draught is adopted, as by a fan or blast, about 18 lbs. is usually required. Common coal may, for practical purposes, be taken as representing carbon. The total heat of coal is equivalent to about 14,500 British thermal units. The mean specific heat of combustion is 0·2375 for constant pressure, and for constant volume it is 0·167.

Thus, the temperature of perfect combustion when a chimney is used for draught purposes $= \dfrac{14{,}500}{25 \times 0{\cdot}2375} = 2440°$ F.

When artificial draught is used, then the temperature

$$= \frac{14{,}500}{19 \times 0{\cdot}2375} = 3210° \text{ F.}$$

And, as will be seen, the temperature for perfect combustion, with only the theoretical quantity of air, would be equal to 4580° F., or nearly double the temperature obtained in actual practice.

374. The evaporative power of such a coal (1 lb. in weight) under perfect conditions would equal 15 lbs. of water from and at 212° F. But, in actual practice, it falls very far short of this amount, as the fuel is wasted in various ways—*e.g.*, (*a*) some of the fuel will go to the ashpit unburnt or partially consumed; (*b*) there is waste in the gaseous state, as is evidenced by smoke, a pure unburnt carbon, issuing from chimneys; (*c*) if air is not supplied in sufficient quantity, the carbon, instead of being converted into carbonic acid gas is only oxidised to carbonic oxide, and if this gas is allowed to go to the chimney, the heat given off per lb. equals only 4400 units, whereas, if the gas is flamed, it supplies the remaining 10,100 units at once—being a colourless gas it is not easily detected; (*d*) a further waste arises from the generation of the draught—a chimney to form a draught sufficient to cause a temperature in the furnace of 2440° F. requires the ascending gases to be of a temperature equal to 550° to 600° F.; (*e*) radiation and conduction are other causes of heat-loss, although they may be reduced by composition being placed round the boilers, &c.; and (*f*) the water in the boilers cannot receive heat until some has been intercepted in heating the material of the boiler, and the heat cannot be applied to the heating surface long enough for the boiler to fully abstract all of it. The loss from radiation and conduction is equal to about 5 per cent.

To obtain perfect combustion, it will be seen that the reduction of air to a minimum is necessary, because an excess goes to form more gaseous products and reduces the temperature.

375. The amount of heat utilised in the ordinary furnace is only equal to about 40 to 55 per cent. of the theoretical heating power of the fuel.

It is interesting to note that the number of thermal units in the gases passing through a furnace at a temperature of 2440° F., available for the heating of the water in a boiler, is equal to nearly five times the number available when the temperature is only 1300° F.

It follows, as a consequence of the higher temperature obtained in the furnace, that the residue, in the form of clinker, will be much less in quantity as well as denser.

The evaporative power of coal has been given as equal to about 15 lbs. theoretically, but in actual practice it is found to be from 7 to 8 lbs., and in some cases it is given as high as 10 lbs., of water from and at 212° F., with the ordinary draught.

376. The amount of refuse available per head of population per annum varies very considerably. In some towns it is as low as 2 cwts., in others it may reach 20 cwts. But in residential districts it varies between 4 cwts. and 7 cwts. Some figures will include the refuse from the shops and trades, others include street sweepings; then, in those towns which have not the water carriage system for the closets, it will include the excreta, which may amount in itself to 8 cwts. per head per annum.

The weight of the refuse varies with the state of the weather and the period of the year. A load of refuse would be quite 20 per cent. heavier in wet weather and in winter than it is in summer. This demonstrates that the amount of moisture is a quantity not to be accurately determined (Art. 372).

377. It is noticeable that, in many designs of destructors, the cell has what is termed a drying hearth. On this hearth the refuse is tipped and is partially dried previous to being burnt on the grate; heat is therefore absorbed from the furnace, but it is claimed that the refuse is in a better form for combustion.

Suppose that in 1 lb. of refuse there is combustible material equivalent to $\frac{1}{8}$ lb. of coal, $\frac{1}{2}$ lb. of moisture, and the remainder incombustible. From the above figures (Art. 375), 1 lb. of coal will evaporate 8 lbs. of water, therefore the $\frac{1}{8}$ lb. of coal in this refuse is capable of evaporating 1 lb. of water; but in the refuse there is already $\frac{1}{2}$ lb. of moisture; the moisture in the refuse itself will therefore absorb half the total heat available, the remaining quantity going to form clinker, waste of gases, and evaporating any water that may be contained in any other vessel—*e.g.*, a boiler.

378. From the experimental tests that have been given to the public, the value of the evaporative power of 1 lb. of town's refuse is given as 1 lb. to $1\frac{1}{2}$ lbs. of water from and at 212°. The per-

centage of moisture in the refuse as it is delivered on to the furnace is rarely given with the analyses, and thus the actual evaporative power of the refuse can rarely be accurately gauged. Every test of the power of a destructor should be accompanied by analyses of the refuse and of the gases in the chimney flue.

The drying of the refuse gives off offensive gases; the course of these gases should be so regulated that they pass through some part of the plant having a temperature of at least 1300° F., so as to ensure their being properly oxidised before they issue to the atmosphere.

379. The amount of combustible matter in a refuse is not at all a constant quantity, but the amount of water evaporated from refuse by certain destructors has been published, and is here given in tabular form:—

Town.	Lbs. of water evaporated by 1 lb. of refuse from and at 212° F.
Leyton,	0·5
Bradford,	0·75
Oldham,	0·95
Shoreditch,	0·99
Hereford,	1·5
Warrington,	1·75
Rochdale,	1·8

A fair average, and one that is acknowledged to approximate closely to actual results, is 1 lb. of refuse evaporates 1 lb. of water from and at 212° F., and to obtain this it will be seen (Art. 372) that the amount of moisture ought not to exceed 30 per cent., and the amount of combustible not less than about 40 per cent.

380. It will be noticed that in destructor installations the boiler —should there be one—is never placed directly round or close to the fire, as it is in an ordinary boiler furnace where coal is used as the fuel. Here coal is contaminated with only a slight percentage of moisture, and the fuel burns easily; but where there is a fairly large percentage of moisture, as in refuse, compared with the combustible, it would not burn so easily, because the combustion gases have to seek the parts of the fuel which are distributed about the refuse, and in the case where a boiler is placed close to the combustion gases, the plates forming the boiler and the water contained therein, being good conductors of heat, would more rapidly abstract the heat, and thus prevent these particles of the fuel from being burnt; hence the fire would gradually die out.

381. It has been suggested that such high temperatures as 2000° and 2500° F. must have a deteriorating effect on the brickwork lining of the cells. Much depends on the quality of the firebricks used for the lining. The author, in erecting some flues for high temperatures, tested the bricks in the following manner:— Samples were obtained of different firms, and a whole brick and

a-half from each firm was placed in a glass furnace. One of them split and powdered in 3 days; another gradually melted away. The latter was, of course, selected for the building of the flues. The manufacturers of some destructors are not in favour of high temperatures, for the reason that the linings would have to be constantly renewed; while others are of opinion that the formation of their destructors are not deteriorated, and that fine particles come from the refuse and form an impervious coat on the brickwork which prevents the heat affecting the lining beyond a certain point. There appears to be good ground for believing that something of the kind does occur.

382. From the foregoing conclusions it is evident that a well-regulated draught is very important when considering the question of obtaining the greatest available heat, and consequently the greatest reduction of a given refuse.

Taking it for granted that there is a given amount of combustible matter in the refuse, let us assume that 1 lb. of refuse will evaporate 1 lb. of water. To obtain this evaporative power would be, and is, improbable when the draught is obtained from a chimney. Recourse has been had to artificial draught, either by a steam blast or a fan.

The usual object of forced draught is to obtain the largest amount of power from a small boiler, which is the reason for its extensive use in locomotives, on torpedo boats, and marine boilers generally. But in the case of refuse destructors, the dimensions of both the boiler and the fire grate may be ample. The fuel, however, is poor, and it is with the object of regulating the supply of air at a given rate to utilise all available thermal power in the refuse that manufacturers have adopted this system of draught.

With forced draught more care has to be exercised in the stoking, for there must be a sufficient depth of refuse on the grate to prevent the air escaping direct into the flues without exercising its functions. There must be no holes in the fire. The depth of the refuse depends on the pressure of the air supplied by the blower.

In the case of the steam blast, it is sometimes brought over the fire, but generally it is placed in the ashpit under the grate.

The amount of power used in bringing about the air pressure is to be obtained from the heat generated, and should, therefore, be deducted from the amount of heat left for power purposes.

The power may be thus calculated:—

Air increases in volume directly as the absolute temperature; it will, therefore, also vary in its weight. The pressure in the ashpit is usually spoken of in inches of water per square foot; 1 cubic foot of water = 62·3 lbs.; therefore 12 inches depth of water on a square inch equals a pressure of 5·196 lbs.

Let p represent the number of inches of draught required to be delivered by the fan.

v = the volume of air at 32° F. per lb. of fuel.
t = the absolute temperature of the air.
x = the area of the fire grate in square feet.
w = the weight of fuel in lbs. per square foot of grate area per minute.

1 cubic foot of air = 0·07609 lb., and therefore 1 lb. of air takes up 13·2 cubic feet of space.

$$\therefore \text{ I.H.P.} = \frac{p \times 5{\cdot}196 \times v \times x \times w \times (t^\circ + 461)}{33{,}000 \times (461 + 32)}.$$

The efficiency of the fan or blower may be taken as equal to 0·3. As about 18 lbs. of air is required for the complete combustion of 1 lb. of coal (Art. 373), and the combustible portion of refuse is equal to coal in the ratio of 1 to 8, it does not necessarily follow that only $2\frac{1}{4}$ lbs. of air are required for the combustion of the refuse, because the calorific parts of the refuse may be but indifferently disposed throughout its mass. It is conceivable that it will be so, and, therefore, more air is required to get at the fuel so disposed.

At Wakefield there is one fan for four cells; the fan is designed to give 8000 cubic feet per minute, and each cell is capable of burning 10 tons of refuse per day, equal to 15·5 lbs. per minute; therefore, the weight of air available is equal to 10 lbs. per lb. of refuse, or taking the lb. of refuse to equal $\frac{1}{8}$ lb. of coal, the supply is equal to 80 lbs. per lb. of coal; but the air only reaches the ashpit at one-third of this rate, which is, therefore, equal to 27 lbs. of air per lb. of coal.

The indicated horse-power necessary for a cell of this capacity

$$= \text{I.H.P.} = \frac{1 \times 5{\cdot}196 \times 132 \times 25 \times 15{\cdot}5 \times (60 + 461)}{25 \times 33{,}000 \times (461 + 32) \times 0{\cdot}3} = 1{\cdot}135.$$

Whatever quantity of heat there is in the refuse there must be sufficient to work the fan. The total indicated horse-power of the fan would be 4·58. A similar fan has been put in at Shoreditch, which gives at the fan a pressure equal to 3 inches, but it is only 1 inch at cells. The actual power of the engine driving the fan would be 1·4 I.H.P. per cell.

383. The use of steam as a means of obtaining a draught is advocated by some designers on the ground that the clinker does not adhere to the fire-bars so firmly as when the blast is from a fan, and that the decomposition of the steam prevents the wearing away of the bars. If this view is correct, the moisture in the refuse when converted into steam should be equally effective. The efficiency is not so good as compared with the fan. The steam supply to the jets necessary for inducing an adequate air supply having to be so ample that the heat in the burning refuse is in-

capable of decomposing more than a portion of the refuse, thus a proportion must be wasted, and it must be to the detriment of the fire in a refuse destructor cell. It is difficult to estimate the quantity of steam required to obtain a given draught, but the author has seen it stated that it is quite five times the amount that would be used to obtain the same draught by means of a fan; this is given with reserve, as the authority is not stated.

384. If the refuse supplied to a destructor be capable of giving off sufficient thermal units to obtain a draught to reduce the organic matter, oxidise the gases, clinker the residue to a hard consistency, and yet leave a number of units available which would otherwise be wasted, these should be put to such use as would give off power in some form; this power is usually obtained by passing the gases through a boiler, and utilising the steam that may be generated in driving mortar mills, small electric plants, &c.

The ordinary Lancashire boiler may be used, or those of the Babcock & Wilcox tubular type. In some cases where there is favourable refuse, large electric or sewage-pumping plants are worked entirely by the heat obtained from the destructors, and the cost of destroying the refuse is reduced considerably.

Suppose 1 lb. of fuel evaporate x lbs. of water per square foot of grate area in one hour, the grate area being y square feet, then

$$x \times y = \text{the amount of water evaporated per hour.}$$

In a non-condensing engine, the amount of steam required per indicated horse-power per hour was estimated by Watt to be 62½ lbs., or 1 cubic foot; but the generally accepted amount is now only 20 lbs. of water. Therefore, the horse-power available from a lb. of fuel which evaporates x lbs. of water per square foot of grate area in an hour

$$= \frac{x \times y}{20} \text{ H.P. per lb. of coal per hour.}$$

Destructor cells have grate areas which vary with the different designs. Suppose a cell having a grate area of 25 square feet, and burning at the rate of 10 tons per day, which is over a 24 hours' trial, equal to 37·2 lbs. per square foot of grate area per hour. Assume that 1 lb. of refuse is capable of evaporating 1 lb. of water per hour.

$$\text{Then } \frac{1 \times 25 \times 37{\cdot}2}{20} = 46{\cdot}5 \text{ H.P. per cell per hour.}$$

Therefore, comparing this with the horse-power required to drive the fan (1·4 I.H.P.), the latter requires 2½ per cent. of the available steam.

385. The amount of water evaporated per hour may be experimentally ascertained thus:—The water in the boiler is kept at a

constant level and pressure, and the amount of water supplied through the feed to the boiler during the test is measured. Then the quantity of refuse put into the cells during this period is weighed, the furnace being, at the end of the test, in the same condition as at the beginning. Then, if a be the number of hours, b the weight of refuse in lbs., and c the weight of water fed to the boiler in lbs. The number of lbs. of water evaporated per hour by 1 lb. of fuel will be $= \frac{c}{a \times b}$.

There are, however, other conditions which bear on this quantity, and which must be taken into account before the figures can be of any value.

The temperature of the feed water supplied to the boiler must be noted, as also must the steam pressure during the trial. The temperature of the feed water may vary between 32° F. and 250° F., depending on the conditions to which the water is subjected. If it is taken from the atmosphere it will have a low temperature, and if it is passed through an economiser it will be at the higher figures; the heat in the water must be taken as it is supplied to the economiser, because the increase in temperature caused by the use of the latter is obtained from the fire. Then the steam pressure will vary slightly; in some cases, however, the pressure may be 50 lbs., 75 lbs., 100 lbs., and in others 150 lbs. It is, therefore, for comparison, necessary to reduce everything to one common standard.

The total thermal units between the temperature t of the feed water and the temperature t^1 of the steam at the average pressure during the trial are divided by the number of thermal units required to raise water at temperature 212° F. to steam at 212° F.

A thermal unit corresponds to 772 ft.-lbs. of energy.

It will be found that to convert

1 lb. of ice at 0° F. to ice at 32° F. = 32 × 0·504 = 16·1 ther. units.
1 ,, ,, ,, 32° F. ,, water ,, 32° F. = Latent heat = 142·4 ,,
1 ,, water ,, 32° F. ,, ,, ,, 212° F. = 212° − 32° = 180 ,,
1 ,, ,, ,, 212° F. ,, steam ,, 212° F. = Latent heat = 966 ,,

By examining these figures it will be noticed that the raising of the temperature of water 1° absorbs one thermal unit; but this does not apply to steam, nor does the temperature of steam rise equally with the pressure—the temperature of steam at any pressure is given in tables. The number of thermal units absorbed by steam for each degree of increase of temperature above 212° F. is about 0·305.

Therefore the total number of thermal units in steam at a temperature $t°$ F. from water at a temperature of 32° F.

$$= 1146 + 0{\cdot}305\,(t° - 212).$$

Example.—Temperature of feed water = 48° F. Water evaporated per lb. of refuse per hour = 1·51 lbs. Average steam pressure = 70 lbs.

The temperature of steam at a pressure of 70 lbs. = 303° F. ∴ The total number of thermal units given off by the refuse was

$$1{\cdot}51\left\{(212^\circ - 48^\circ) + 966 + 0{\cdot}305\,(303^\circ - 212^\circ)\right\} = 1748{\cdot}6$$

and the number of lbs. of water per lb. of refuse per hour, which would be evaporated by these units from a temperature of 212° F. to a steam temperature of 212°

$$= \frac{1748{\cdot}6}{966} = 1{\cdot}81.$$

386. Let us now consider the number of thermal units which are required to keep the destructor working, and obtain, if possible, the number to be given off for power purposes.

The draught we may take as equal to 1 inch of water in the ashpit, and the temperature of the gases going to chimney as 600° F.

$\therefore\ 1 \times 0{\cdot}2375 \times 600 = 142{\cdot}5$ thermal units wasted.

By radiation and conduction = 80·0 „ „ „

By absorbing x per cent. moisture in refuse to steam at 212° F., the initial temperature of the refuse being, say, 60° $= (212 - 60 + 966)\,\dfrac{x}{100}$ thermal units wasted.

In making clinker, reckoning melting point 1200° and specific heat 0·190, and y representing the proportion of incombustible $= 228\,\dfrac{y}{100}$ thermal units wasted.

No. of thermal units for useful work $= z$.

The addition of these $= 222{\cdot}5 + \dfrac{228y}{100} + \dfrac{1118x}{100} + z$, which represents the full thermal value of 1 lb. of refuse. It has been stated that 1 lb. of refuse = $\frac{1}{8}$ the value of coal; ∴ the number of thermal units in 1 lb. of refuse $= \dfrac{14{,}500}{8} = 1811$.

To illustrate the quantity of useful work obtained from a refuse which contains 40 per cent. combustible, 30 per cent. of moisture, and 30 per cent. clinker,

$$\text{Then } z = 1811 - \left\{222{\cdot}5 + \left(\frac{228 \times 30}{100}\right) + \left(\frac{1118 \times 30}{100}\right)\right\}$$

$$z = 626{\cdot}3.$$

Now, suppose the feed water was at a temperature of 53° F.; then the number of thermal units required to raise 1 lb. of water at 53° F. to steam at 212° F. = 1125. Therefore, this refuse is only capable of supplying heat enough to raise 0·55 lb. of water to this steam temperature.

But it has been shown by experiment that 1 lb. of such a refuse is capable of evaporating 1 lb. of water to steam at 212° F., the work of absorbing moisture, &c., being included. Therefore the calorific value of 1 lb. of such a refuse must be greater than $\frac{1}{8}$ lb. of coal, and must be nearer a quarter of its value, which means that 62 per cent. of combustible material in the refuse of the above experiments must have the full calorific value of good coal.

Knowing the percentage of moisture, of combustible and of incombustible material, the approximate quantity of heat available can easily be ascertained.

387. In comparing designs of destructors, the following data should be known in order to fully consider their respective merits:—

1. The grate area.
2. Amount of refuse burnt per square foot of grate area.
3. The fumes of the refuse as it is being dried must pass over the hottest part of the furnace or combustion chamber.
4. The lowest temperature of the furnace or combustion chamber must be 1300° F.
5. The temperature of the combustion chamber (if separate from the furnace).
6. The temperature of the flue at the chimney.
7. The analysis of the gases at the flue. (There should be as little as possible of carbon monoxide (CO), less than 1 per cent., and free oxygen and nitrogen should bear a somewhat close approximation to the proportions in atmospheric air near to the flues; the carbonic acid (CO_2) should be as high as possible; 6 per cent. is often obtained, and 15 per cent. will be about the maximum.)
8. The temperature of the feed water.
9. The pressure of steam generated.
10. The amount of water evaporated per lb. of refuse burnt per hour. (8, 9, and 10 may be substituted by the amount of water evaporated per lb. of refuse per hour from and at 212° F.)
11. The amount of steam used by the steam blast or fan or blower, and the weight of draught of air in inches of water.
12. The weight of residue—*i.e.*, clinker and flue dust.
13. The cost of labour per ton of refuse delivered.
14. The cost of, per ton, interest and sinking fund.
15. The cost of maintenance.
16. The number of men required to work the destructor.
17. Is the labour required to be more skilled in one type than another?

18. Method of filling.
19. Is an inclined road required?
20. Height of chimney required.
21. The quality of refuse compared with that under consideration—as to combustible, incombustible, and moisture.
22. The disposal of the clinker and flue dust.
23. The revenue from such disposal.

The first consideration must have reference to the reducing of the organic matter, the oxidation of the gases and the lessening of the clinker, the steam-raising plant being a secondary matter.

A balance-sheet should be made which on one side should have:—

1. The sinking fund and interest on capital per annum.
2. The cost of labour per annum.
3. The cost of maintenance per annum.
4. Disposal of residue per annum.

A sale of the clinker and flue dust would be on the other side of the sheet, which would include:—

1. Revenue from distribution of steam generated or per lb. of water evaporated per annum, less the amount used for fan or blast.
2. Revenue from disposal of trade refuse per annum.
3. Revenue from disposal of residue per annum.

The cost per ton for the items on both sides of the sheet would be useful in comparing with what other destructors are doing.

388. It has been the object, when laying down a refuse destructor plant, to arrange that the power available from the heat thereby obtained should be mainly used in aiding electric-power plants and sewage-pumping machinery. The steam is also used in working disinfectors, such as Washington Lyons' machine. But there are cases where the destructors have to be placed in such positions that the power is not so available. Then, unless some machinery requiring steam power can be found to utilise the heat, it will be wasted, and a source of possible revenue lost. In such case the cost of disposal of the refuse is, in a sense, increased.

The power may be used in the manufacture of goods and articles which may have a ready sale, and be in fairly constant demand.

As the amount of the clinker is about 30 per cent. of the total amount of the refuse burnt in the destructor, it will be seen that the disposal of this residue should, if possible, be made remunerative. Should a visit be paid to destructor stations, it will be found lying there in a large mound, but closer observation indicates that the clinker is in such quantities as to be difficult of disposal, and is consequently sent to a tip.

At Bradford, previous to 1894, the expenditure was at the rate of £1000 per annum for the disposal of the clinker—*i.e.*, at the rate of 1s. 5d. per ton. Similarly at Glasgow the amount paid was at the rate of 1s. 6d. per ton, whereas at Bradford the revenue is now at the rate of £500 per annum, and at Glasgow they are obtaining about 3d. per ton for the clinker.

By laying down a mortar mill in conjunction with a boiler, the heat is utilised in many places for making mortar, which has a sale of from 5s. 4d. to 6s. 6d. per ton. Stone-breaking machinery has also been laid down, and the power used up in this manner.

The dust from the flues forms a fairly good base for the making of disinfecting powder, and has a value fully equal to the labour of collection.

389. At Liverpool, Birmingham, Bristol, Bradford, and other places, Musker's patent concrete flag machinery has been installed, and flags made from a combination of Portland cement and the broken clinker at a cost of about 1s. 9d. per yard, and sold at Bradford at the rate of 3s. 2d. per yard. The Liverpool machine is capable of an output of 232 yards per week; they wear well, are never slippery, and can be cut or tooled like stone.

In smaller towns where the demand for flags and mortar is known there would be no difficulty in ascertaining to what extent a further supply was needed. Similarly, clinker for concrete is not often required, except where large contracts are in hand, such as foundations for walls, tramway road construction, foundations for engine beds, &c. At Bradford the clinker is crushed by machinery into four sizes, the finest of which is eagerly taken by plasterers in preference to washed sand; other sizes are used for the making of concrete (the foundations for the electric light station and the tramways took a very large quantity). It is also used by the sewage and street cleansing departments. The sale is at the rate of 8d. per ton.

But there are other articles which may be made from the refuse, and as the power is generally more than necessary to crush the clinker and make mortar, &c., heavy and more powerful machinery may be requisitioned to make goods which in all probability may also bring in a greater profit and create a demand.

Mr. M'Taggart, the Cleansing Superintendent to the Bradford Corporation, in a paper read before the British Association for the Advancement of Science, in September, 1900, showed that he had at his disposal a considerable amount of power from refuse destructors which is not used for electric light purposes; indeed, the Bradford Corporation do not consider it advisable to use it for such work as the calorific value of the refuse is so variable.

The experience of other towns differs from this opinion—*e.g.*, the Corporation of Darwen has an electric light station, which, up to the present, has not required any coal to generate the heat necessary to keep their works in operation, the heat being wholly obtained from the destructors.

Mr. M'Taggart, during a fortnight's test of 12 cells of a destructor, obtained 29·36 per cent. of residue, equal to about 380 tons. The heat available was utilised in making 880 tons of saleable material in the form of mortar, crushed clinker, concrete flags, and fish guano, the value of which was £148.

It will thus be noticed that the power given off was more than capable of dealing with the clinker that the destructive cells left as a residue, and it evidently (from their installation of other machinery and from experiments to be described) has been the desire of that Corporation to convert the clinker into some other substance which shall require and use up the power that is now being wasted, or that is likely to be wasted.

390. The installation for the making of artificial stone comprises a powerful hydraulic press working at a pressure of 2 tons per square inch. In conjunction with the press are two moulds, which enable the press to keep working continuously, one mould being filled while the other is being pressed. The machine is capable of pressing 200 slabs per day of nine and a-half hours.

The slabs are also made in a variety of ways, some with a facing of granite chippings and Portland cement ¾ inch thick, in the proportion of 3 to 1. The remainder of the slab, which is 2½ inches thick altogether, being composed of clinker and cement in the same proportion. The slabs are also made from clinker and cement alone. The faced slabs are sold at the rate of 3s. 2d. per superficial yard, and the other at a much cheaper rate, they being very suitable for flagging cellars, back yards, and side streets.

The results of tests which these artificial stones were put to are given on p. 267.

Nos. 1 and 2 were made in May, 1900; from 3 to 10 in March, 1900; 11 and 12 in October, 1899. Nos. 13 and 13*a* samples were supplied to the Bradford Corporation in May, 1900, and they compare well with those made by the Bradford Corporation. The dates of tests were August 10 and 11, 1900. There is considerable difference between Nos. 1 and 1*a*, and Nos. 9 and 9*a*. The latter appear to be more accurate than the former, as they agree well with the strength of Nos. 2 and 7.

391. Mr. M'Taggart has also been experimenting in the making of concrete bricks from the clinker on behalf of the Bradford Corporation, and the results have been so satisfactory that it is intended to lay down one or more plants at some of their new destructors. The bricks can be produced in any size or colour. The machinery is not expensive, and no drying kilns are necessary. They are made with 10 per cent. mixture of hydraulic lime and clinker; when properly seasoned, they are stronger than the ordinary building brick in Bradford, and only cost 14s. per 1000. A small machine will turn out 8000 bricks per day, and will require over 20 tons of clinker. If the drying space be limited,

No.	Description.	Proportion.	Ultimate crushing strength. Tons per sq. foot.		Transverse Tests.		
						Load in lbs.	Deflection at centre in inches.
1	Granite chippings and Portland cement,	3 to 1	85·1	Size of block, 2·5 inches x 2·5 inches x 2·5 inches. *Area, 6·25 inches.*	Each slab was originally 10 inches in breadth and 2½ inches in thickness, the distance between the supports being 1½ feet.	269	0·18
1*a*	Do.,	,,	34·04			...	...
2	Bluestone chippings and P. cement,	,,	184·46			963	0·20
2*a*	Do.,	,,	139·84			...	...
3	Hard Yorkshire stone—Lightcliffe,	...	335·57			1478	0·15
3*a*	Do.,	...	298·54			...	...
4	Threlkeld granite, Keswick,	...	186·3			1279	0·11
4*a*	Do.,	...	129·95			...	...
5	Clinker and P. cement,	3 to 1	128·03			1165	0·16
5*a*	Do.,	,,	150·88			...	...
6	Do.,	4 to 1	93·38			403	0·16
6*a*	Do.,	,,	81·88			...	...
7	*Facing*—Granite chippings and P. cement,	3 to 1	189·52			1478	0·12
7*a*	*Body of Slab*—Clinker and P. cement,	,,	158·47			...	...
8	Same as No. 7,	4 to 1	87·40			493	0·15
8*a*	Do.,	,,	100·74			...	...
9	Granite chippings and P. cement,	3 to 1	199·64			1254	0·10
9*a*	Do.,	,,	178·02			...	...
10	Do.,	4 to 1	99·82			493	0·22
10*a*	Do.,	,,	120·75			...	...
11	Same as No. 7,	...	133·17			560	0·12
12	Yorkshire stone slab, Quarry gap, Bradford,	...	411·04			2486	0·06
12*a*	Do.,	...	322·46			...	...
13	Same as No. 7—made by Bootle Corporation,	...	192·28			1523	0·15
13*a*	Do.,	...	168·82			...	...

they may be dried, hardened, and made ready for use in eight hours by the use of high-pressure steam. The results of tests show that they should be kept at least three months before being used (if they are naturally dried), the increase in strength during the last four weeks being remarkable.

The tests were made at the Technical College at Bradford. Further experiments have also been made by Mr M'Taggart for utilising the clinker in a profitable and artistic way, in the manufacture of ornamental tiles, which require special but inexpensive machinery, one man being capable of producing 750 encaustic tiles or from 3000 to 4000 plain tiles per day, each tile being subjected to a pressure of 60 tons. The sale of these at the usual prices quoted for similar goods leaves a very handsome profit indeed.

Description.	Sample.	Original dimensions in inches.			Area in sq. feet.	Ultimate Crushing Strength.				Remarks.
						First crack.		Completely crushed.		
		Length.	Breadth.	Thick-ness.		Total tons.	Tons per sq. foot.	Total tons.	Tons per sq. foot.	
Ordinary pressed brick, . .	1	9·0	4·4	3·1	0·275	36·31	132	50·76	184·6	Age unknown.
	2	8·9	4·25	3·1	0·262	...	...	53·16	202·9	
Destructor clinker, 10 per cent. Portland cement, . .	1	9·8	4·7	2·4	0·32	19·61	61·3	24·84	77·6	Made 10 weeks.
	2	9·8	4·8	2·4	0·33	9·86	30·2	24·49	75·1	
Destructor clinker, 15 per cent. Portland cement, . .	1	9·3	4·6	3·1	0·29	22·91	77·1	28·54	96·0	,,
	2	9·3	4·6	3·0	0·29	11·31	37·7	19·01	63·0	
Destructor clinker, 15 per cent. hydraulic slaked lime, . .	1	9·9	4·7	2·5	0·32	27·7	80·5	38·11	119·0	Made 14 weeks.
	2	9·9	4·6	2 6	0·31	...	...	25·58	82 5	
Destructor clinker, 15 per cent. unslaked hydraulic lime, .	...	9·6	4·8	2·8	0·32	32·14	100·4	36·22	113·2	,,
Destructor clinker, with 15 per cent. slaked hydraulic lime,	...	9·6	4·9	2·9	0·34	54·14	159·2	75·48	222·0	,,

392. The Bradford Corporation are now erecting a new form of destructor, which will hold, in an inverted hopper, 12 or 14 hours' supply of refuse. The mouth of the hopper is to be closed with a heavy cast-iron door, easily opened and as easily closed. The clinker will be removed from the furnace in the ordinary way, but will be taken from the front of the furnace by an overhead railway. When the destructor is complete it is expected that the refuse will be dealt with without nuisance, and it is estimated that the cost of the destruction of the ashpit refuse will be 5½d. per ton only, whereas the cost is now about 9d.

393. The question of laying down plant for the manufacture of the goods here mentioned must be subordinate to the demand for the article. There is no doubt that there would always be a demand for bricks, especially if the price is less than 20s. per ton. Tiles are not greatly in demand, except in a town where building operations are proceeding with vigour, and in such a town it would be more probable that mortar, concrete, and clinker in a crushed form would be required in large quantities.

394. Where sewerage works are in progress and the demand for the clinker otherwise than heavy, it is probable that it might be used in forming concrete pipes or culverts.

Clinker, as such, is not often demanded in small towns, but a stock ought always to be kept.

395. The power obtainable from the heat generated having been calculated, after allowing for the quantity that would be used in the machinery attached to the installation, may be stored or delivered to works, buildings of any class, &c., outside the immediate vicinity of the destructor installation. In New York steam is transmitted through many miles of pipes which are covered with a suitable non-conducting composition reducing the radiation and loss of heat to a minimum; in fact, the loss is very small. It will be seen, then, that houses and business premises might be heated and possibly small manufacturers' workshops supplied with steam for their machinery.

The heat so transmissible from a refuse destructor would only be available over a limited area, except in those districts where there were large installations.

There should be some means of storing the power. It has been stored by being converted into electricity and passed into accumulator batteries. This, however, is wasteful, as there must be loss through the machine converting the power and through the accumulator batteries.

At a gas-works the retorts are at work all day and through the night with a speed equal to the average consumption of gas during the whole of the day, but as the gas is only used at night, it has to be stored in holders; so that when the demand is high the supply is available without causing the retorts to be increased in number and an excess number of men employed.

Mr. Druitt Halpin has devised a scheme of storing the heat from boilers which has been proved to be a success in an installation put down at Shoreditch. Here there are erected several storage tanks constructed to withstand great internal pressure. The water in the boilers is converted to steam, passed through the storage tanks, which are filled with water (the initial temperature of which is that of water under ordinary conditions, or that due to passage through an economiser, as at Shoreditch), which is raised in temperature to about 400° F. The outside of the shell of the storage vessel is highly insulated with a non-conductive substance to counteract radiation, &c. The steam used direct from the boilers is at a temperature of about 350° F.

It will be noticed that it is water that is held in the reservoirs at the temperature of 400° F., which must not be confounded with steam. The boiling point of water is 212° F. at the sea level, but at a higher level the boiling point is appreciably less, on account of the reduction in the atmospheric pressure at that point; similarly, if the vessel containing water is put under higher pressure than the atmosphere, the boiling point may be increased to a greater figure.

The difference between the temperatures of the steam from the boilers and of the water in the reservoirs is then 50° Every pound of water falling in temperature through this range releases 52 thermal units, thus:—

Total heat required to raise 1 lb. of water
from 32° to 350° F. = 247,886 foot-lbs.
„ 32° to 400° F. = 287,829 „

772) 39,943 difference in foot-lbs.

52 thermal units.

The latent heat in converting water at 350° F. to steam at the same temperature is found thus:—

Thermal units in water at 350° F. = 321
„ „ steam at 350° F. = 1189

∴ Latent heat = 868 thermal units.

Therefore, the number of pounds of water falling in temperature from 400° to 350° F. required to yield 1 lb. of steam = $\frac{868}{52}$ = 13. Allowing for losses, this might be increased to 15 lbs.

Suppose that the power given off from a series of destructor cells was found to be on an average equal to 100 H.P. every hour during the day, and that the engines of an electric light (or sewage pumping) station to which the destructor was supplying heat had only a small day load but a very heavy night load (averaging, if spread over the day, 100 H.P. per hour), then, by constructing x reservoirs 30 feet long and 8 feet diameter, each of which would contain 84,000 lbs. of water heated to the temperature above stated, their capacity would be equal to 5600 x lbs. of steam at a temperature of 350° F. = 135 lbs. pressure; this amount represents 280 x H.P. hours. The unknown quantity x depends on the excess of the maximum load over the average load which these reservoirs must be capable of supplying.

Suppose there were five hours when the load was above the average, and during that time the quantity x was four times the average, then provision would have to be made for 1500 H.P., which would mean six reservoirs of the size mentioned.

396. The tanks may be used for the storing of hot feed water for the boilers. Professor Unwin states that if boilers are fed through these storage tanks instead of direct into the boilers from the economiser or feed tank, the saving in efficiency is equal to nearly 20 per cent. Another advantage in both methods is that the scale in the boilers is reduced to a quantity practically inappreciable; that the deposit is left in the storage tanks in so easily removable a condition that it may be blown out. At Shoreditch the scale found, after seven months' working, at the bottom of the storage tank was about 12 inches deep, soft, easily removable, and in layers of 3 inches thickness; the boilers and economiser were in fact, practically clean.

397. There is a large amount of dust in the refuse which, should it be discharged into a refuse destructor, will, unless provision is made, be drawn by the draught into the chimney, and issue into the atmosphere. There should, therefore, be a contrivance in the flues to the chimney which would prevent this dissemination of particles on to the leaves of trees and into the inhaled atmosphere. Dust chambers are provided in most destructor flues. Sometimes they consist of baffling walls or plates, or by some means the gases are made to pass vertically upwards, then sideways along a passage until it reaches the chimney. But it would appear that by simply increasing the sectional area of the flue to the chimney three or four times through a length of about 20 feet of the flue and placing bafflers at the entrance and exit, the dust would be effectually stopped, as the speed of the gases would then be reduced either one-third or one-fourth as the case may be; the bafflers being merely a means for ensuring the diversion of the gases through the chambers.

398. In choosing a site for a destructor, there are several points which require careful consideration. If a destructor be built in the midst of a thickly-populated district, the carriage of the refuse through the streets is greatly diminished, but, if the refuse is stored for any length of time, the noxious smells will be apparent to a greater number of the inhabitants. This in a well-

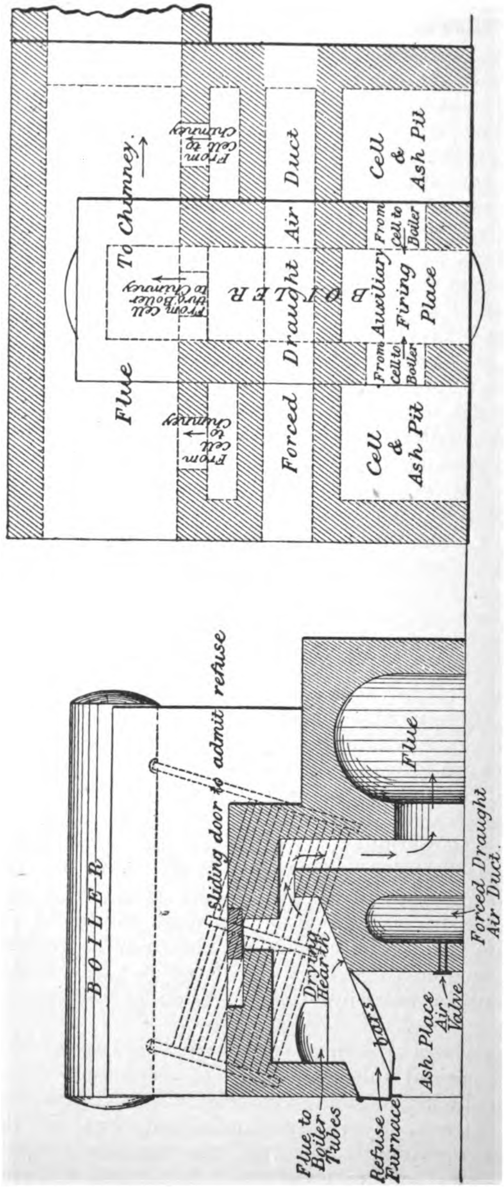


Fig. 173.—Manlove, Alliott & Co.'s destructors.

designed arrangement should not occur; in fact, if a smell issues from a destructor, it fails in its object. If the destructor should be placed outside the residential district, greater expense is incurred by the extra carriage. Most destructors occasionally emit gases with a peculiar odour, which may be due either to faulty design or to bad stoking; it is better perceived at some distance (say, half-a-mile) away from than close to the works, and naturally so, because the gases from the chimney would not generally reach the atmosphere near the ground at a less distance. It is therefore desirable that a chimney should not be placed in a position that the prevalling winds would carry the fumes or gases anywhere near the residential portion of the district. In order to prevent annoyance, destructor chimneys should be, and usually are, about 60 yards high. Should such a chimney be built, allowance may be made for the amount of draught it is capable of creating when a fan or steam blast forms part of the apparatus. When a fan or steam blast is used the chimney need not be more than 40 or 50 feet high.

399. There are several designs of furnaces in operation; illustrations of them are here given, with a short description.

Fig. 173 shows Fryer's destructor, as recently built by Messrs. Manlove, Alliott & Co.; each cell has a grate area of 25 square feet, with a dead hearth of another 25 feet. The refuse is deposited on to this latter hearth by means of Messrs. Boulnois & Brodie's truck, into which the refuse is tipped from the cart; the truck is divided into six compartments, each of which is capable of holding one charge, which, when desired, can be discharged into the cell by the turning of a crank; a saving of labour is thus gained, as the refuse is not handled until it is in the cell. The refuse is allowed to dry on this dead or drying hearth, and the fumes may (if the boiler which is placed between the two cells is not in operation) go direct to the flue, as shown in the sketch, without passing over any of the fire where the red-hot cinder is lying; it has merely to pass and intermingle with the gases, which may be of so high a temperature as will ensure their being oxidised, but there is a possibility of some fumes passing unburnt to the chimney. When, however, the boiler portion of the apparatus is in operation, the gases pass over the burning refuse on the grate, and will be oxidised. The air is supplied by a fan worked at the end of the cells, and is delivered in each ashpit; the draught may be regulated by the man who is stoking. Only one-third of the furnace door may be opened at a time, but the whole width of the furnace may be opened out when the clinker is to be removed. The temperature of the gases in the flues is at least 1500° F.

400. Fig. 174 shows the Horsfall destructor, which differs but slightly from that of Messrs. Manlove, Alliott & Co. All the gases from the drying hearth and the furnace pass to the front of the

cell. In both these destructors the charging of the cells may reduce the temperature and cause a portion of the gases to escape unburnt to the flue, and would only be oxidised by the high temperature of the gases passing to the chimney from the other cells. The boiler is situated at a distance from the destructor cells. When built in

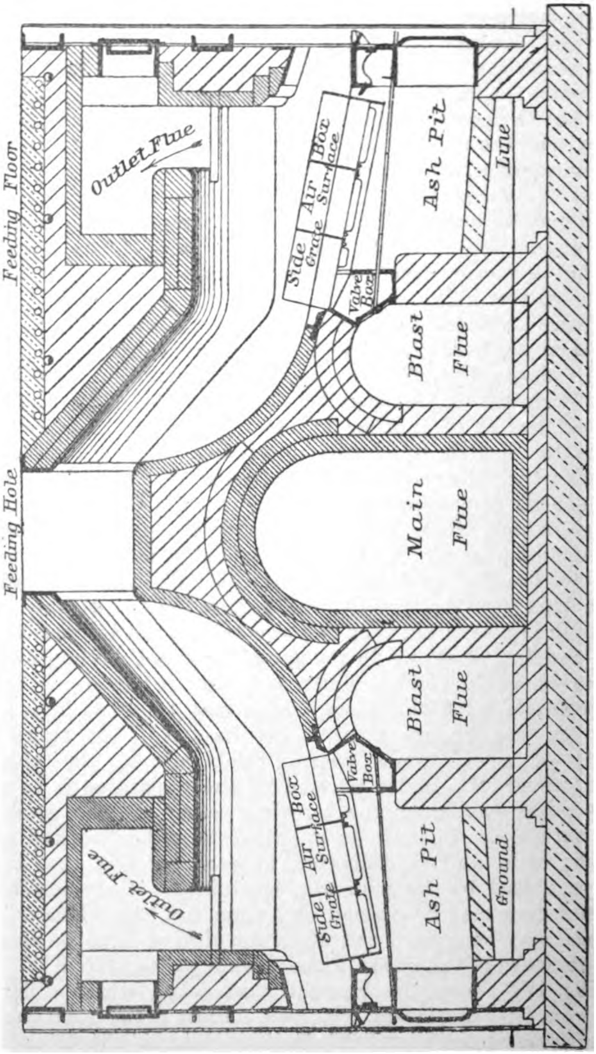


Fig. 174.—Horsfall destructor.

single series, the feed hole is at the rear of the cell, about 3 feet above the level of the fire doors. Forced draught is used. The temperature of the gases in the flues is over 1500° F.

401. Fig. 175 shows the Beaman & Deas destructor. The refuse is fed sideways through the feeding hole A, and the escaping gases are passed over the fire on the grate area, on which is the bright cinder. In this form also, unoxidised gases may escape to the flue when an extra heavy charge is tipped into the furnace owing to a lowering of the temperature. The temperature in the flues in this destructor often reaches 2000° F.

402. Figs. 176, 177, and 178 show the Meldrum destructor, which differs considerably from those just described; the cells are placed side by side, but there is no dividing wall between each; thus, inside, the appearance is that of one large furnace; there is an ashpit to each cell, and a separate steam air blast is also provided. In the arrangement shown there are four cells, and the charges are thrown on to the fire by hand from a hopper erected opposite the cells. Each cell may be treated separately so far as the firing of the refuse is concerned, but care should be exercised that two of the fires should be at their full calorific capacity in order that the fumes from the other fires just charged should mix with the gases at a sufficiently high temperature. The gases from the freshly-charged cell or cells nearest the combustion chamber may pass to the chimney without being oxidised (as in the cases already mentioned), should the fires in the remaining cells yield less than the amount of heat required for oxidation. The temperature obtained

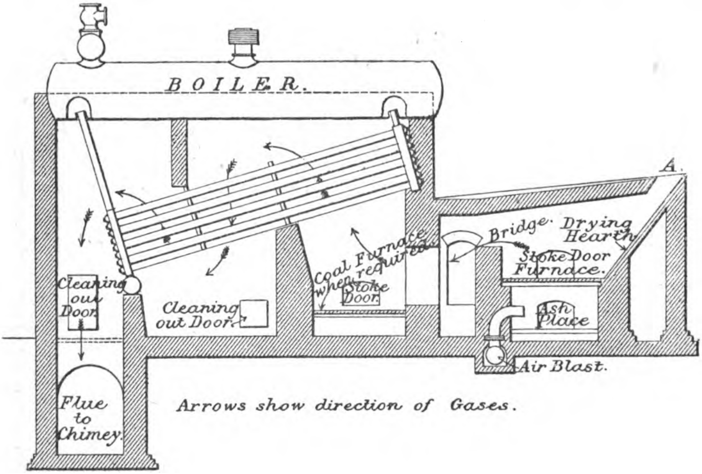


Fig. 175.—Beaman & Deas destructor.

in these destructors also reaches 2000° F. A feature of this system is the heating of the air supplied in the air draught by the heat remaining in the escaping gases. There is also another difference between this destructor and the others that have been

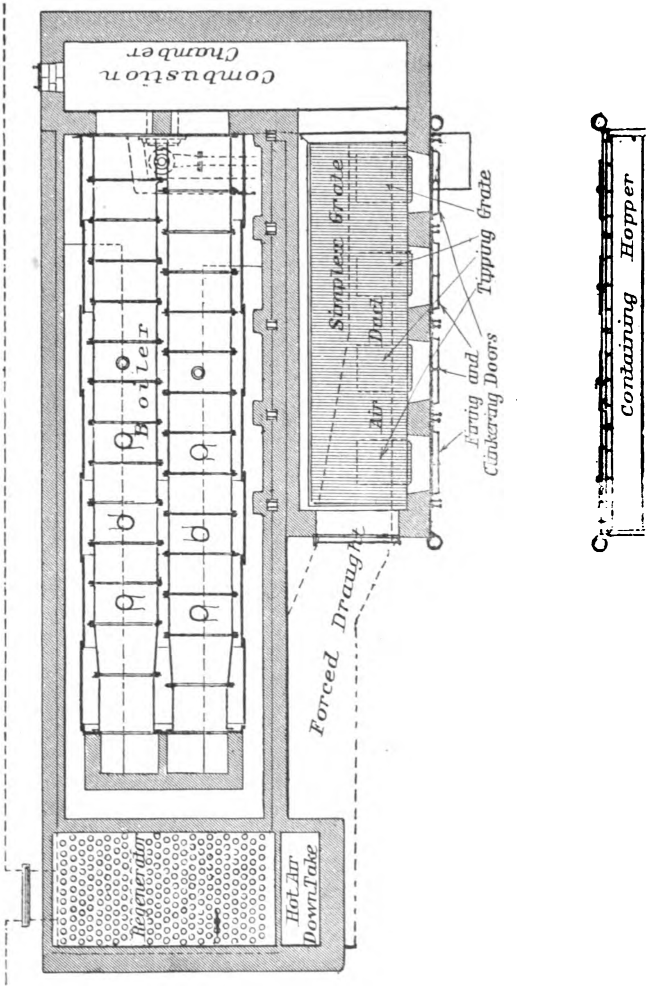


Fig. 176.—Meldrum destructor (plan).

described in that the refuse is not dried on a hearth previous to being burned.

403. Fig. 179 shows Heenan's patent twin-cell destructor. In

this form of destructor the cells are built in couples. The refuse is tipped on to a stage, and the furnace filled through the openings J

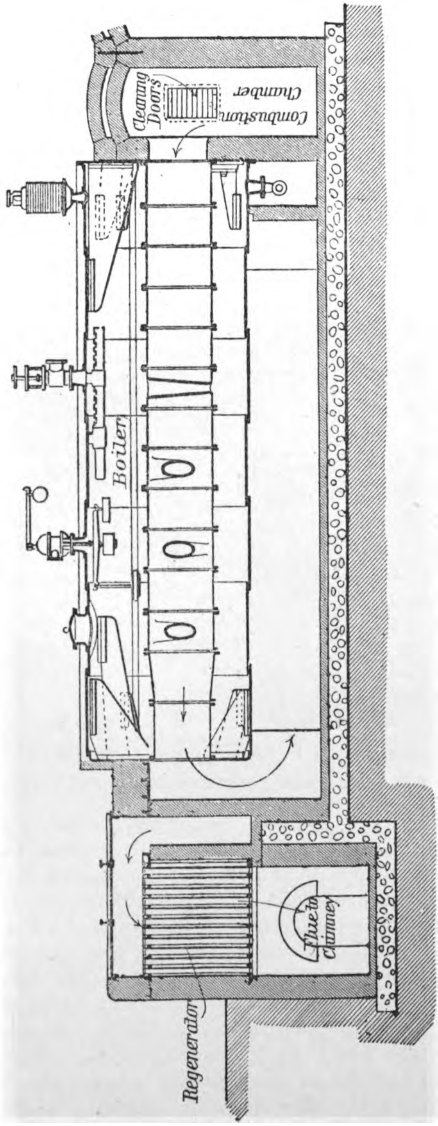


Fig. 177.—Meldrum destructor (section).

at the back of the cells, the doors for stoking being placed in front, as indicated by the letter K. The refuse having been previously placed on the grate of cell D attains (with the aid of forced air draught) a temperature of from 1500° to 2000° F., and passes along the flues to E F and on to the chimney, or, as required, to the tubes of boiler B through G and H. The refuse is then placed in C, and the fire started; the fumes must pass over the furnace D to get to the flue; when the refuse is burnt out the temperature in C has risen to 1500° F., and the damper E is turned over; D is clinkered and refilled, the fumes from this furnace passing over the now vigorous fire in cell C. The method of filling the furnace at J does not appear to be good, as the fumes must rise direct into the atmosphere. The space taken up by the destructor is very small, but the amount burnt per cell is about 10 tons per day.

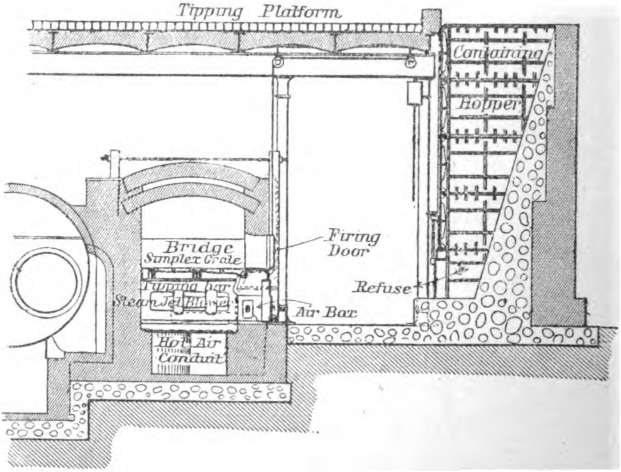
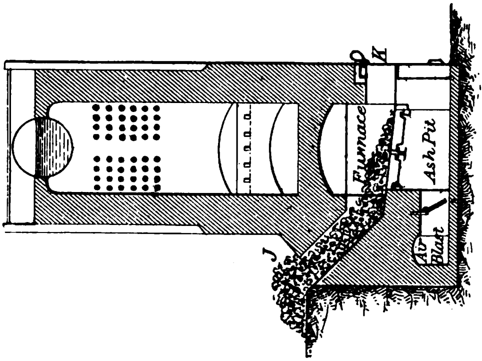


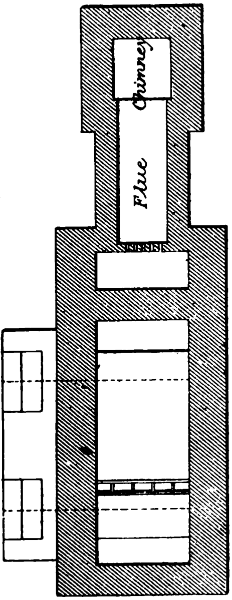
Fig. 178.—Meldrum destructor (section of hopper).

404. Fig. 180 shows Baker's refuse destructor. The refuse is tipped on to a platform, and is discharged by manual labour through the door G down an incline, which is steep enough for the refuse to gravitate on to the fire grates. The fire is aided by an induced draught or by a supply under the grate. With the induced draught the air supply is obtainable only through the door at the tipping platform, as the ashpit and stoking doors are air-tight. Thus the fumes from the drying of the refuse are drawn through C down the side walls to the fire-bars, while the small flue D takes the excess fumes direct to the flue; the gases from the combustion chamber pass through the flue B and through the tubes of the boiler, or may be diverted through the flue A to the chimney when the boiler is

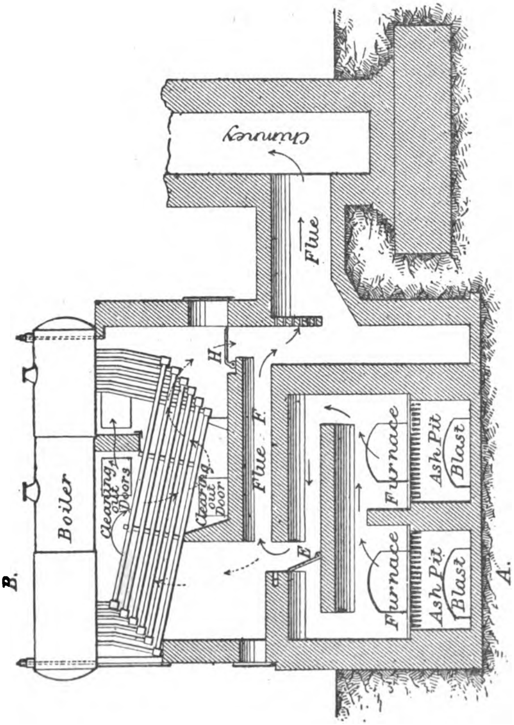
not required. This destructor, like those previously described, is faulty, inasmuch as it may sometimes allow unoxidised gases to pass from the drying hearth to the flues.



SECTION A.B

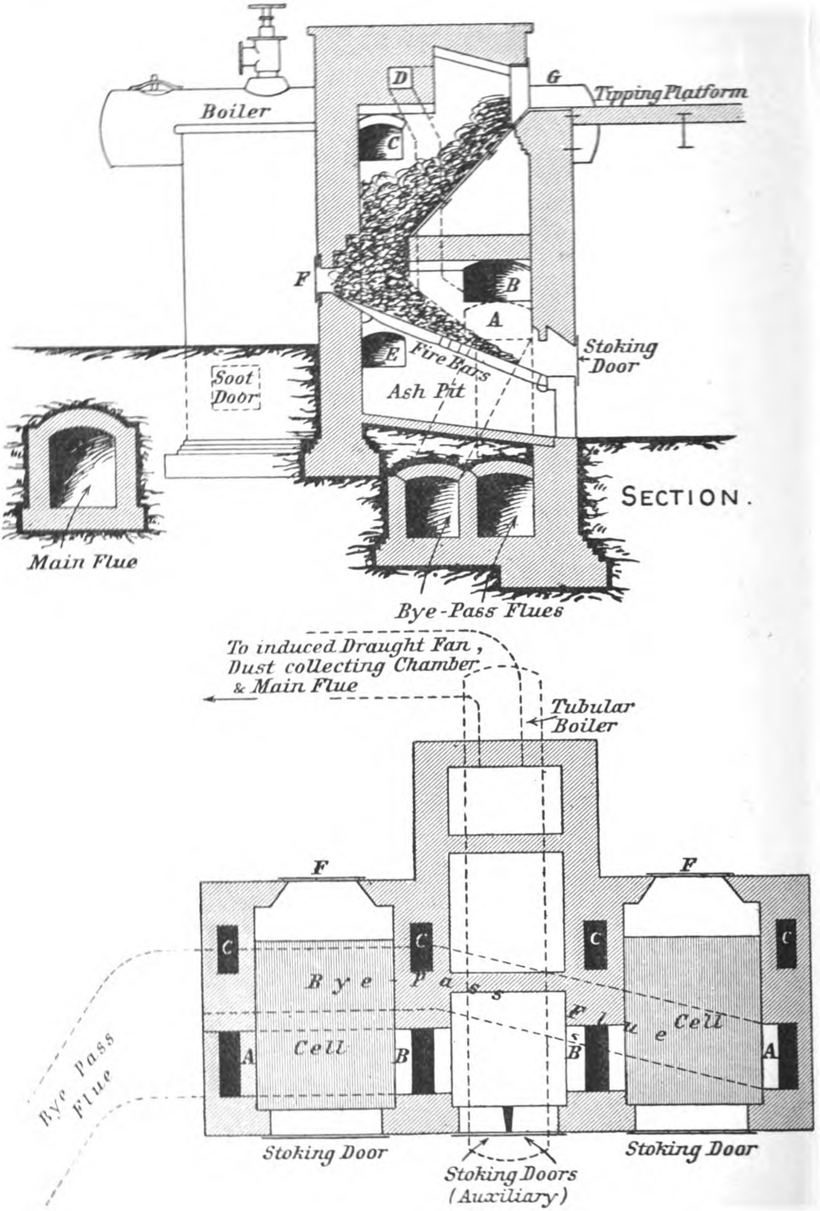


PLAN AT 12" ABOVE GROUND LINE



LONGITUDINAL SECTION.

Fig. 179.—Heenan destructor.



SECTION.

PLAN.

Fig. 180.—Baker's destructor.

405. There are other processes for destroying the noxious nature of refuse. One is in the form of a retort, into which the refuse is tipped and the cover sealed. The air is prevented from entering by a water seal at the foot of the retort. Heat is applied at a high temperature, and the gases conveyed to a receiver; at the close of the process this seal is withdrawn and the residue removed through the openings then left in the retort. The experimental results have not received much favour.

In New York the refuse is collected and sent to Barren Island, where it is treated by dry steam. The cauldrons or digesters into which the refuse is deposited are built of steel and have a capacity of 10 tons; water is added, and high pressure steam passed into the bulk. All fat and grease rises to the surface, and is taken off; the boiling is continued until the consistency is like syrup; it is then removed, and easily transported as manure, which has a sale at the rate of about 33s. per ton. The manure is inoffensive in odour. The fat is sold for soap-making. Bottles, boxes, &c., are separated before the refuse is treated, and are also disposed of. All gases which may issue are removed by means of a fan, and washed before passing into the atmosphere.

CHAPTER XX.

CHIMNEYS AND FOUNDATIONS.

406. A CHIMNEY is constructed in order to obtain a draught of air through the fire grate of a furnace which will be sufficient to ensure the perfect combustion of the whole of the calorific material in a fuel.

Forced draught, either by fans, blowers, or steam blast, is now used very extensively, and therefore the reason for the great height common to many chimneys in the past has disappeared. But, as the gases and smoke must have an outlet, local authorities insist that the height of a chimney shall be at least 90 feet in height in order that the fumes and carbon may be delivered in an atmosphere out of the breathing zone, or that it shall receive such a mixture with the air that it will not be so unpleasant to the senses should it enter this zone. The gases issuing from chimneys erected in connection with refuse destructors are liable to give off obnoxious smells, and it becomes advisable that the gases should be taken to such a height in the atmosphere as will prevent the probability of complaint being made.

407. From Art. 167 we learn that when air is heated it expands —that is, it is less dense than the cooler air around, and therefore it will rise. The air in the enclosed space of a chimney will always be warmer by some degrees than the outside air; it will therefore be lighter, and rise to the top of the chimney; the outer air, being under greater pressure, rushes in at any opening at the foot of the chimney. When the air in the chimney is heated, its speed will attain to a very high velocity, which is represented by the following formula :—

Let h = height of chimney in feet, t temperature of the air at the top of the chimney, t^1 the temperature of the air supplied to the chimney, v = velocity in feet per second.

$$\text{Then } v = 36{\cdot}5 \sqrt{h\,(t^1 - t)}.$$

To determine the sectional area of the main flue and chimney.

Let H.P. = the indicated horse-power of engine or boiler,
h = height of chimney,
a = area of fire grate in square feet,
w = weight of coal consumed per hour in lbs.,
A = sectional area of top in square feet.

$$A = \frac{0{\cdot}1045\,w}{\sqrt{h}} = \frac{1{\cdot}25\,a}{\sqrt{h}} = \frac{0{\cdot}7\ \text{H.P.}}{\sqrt{h}}$$

408. *General Rules.*—Where boilers of 300 H.P. capacity and refuse destructors burning about 10 tons per cell per day with a grate area of 25 square feet discharge the fumes into a chimney, the sectional area is about 6 superficial feet per boiler or per cell. The area is also somewhat approximately found by dividing the area of the grate by 8 or 10, the area for refuse destructor chimneys being found similarly, but the divisor will be 4 instead of those given for boilers.

409. The important factors in the stability of a chimney are (1) its weight, (2) its height, and (3) the pressure of the wind.

The diameter of a chimney at the base is for brick chimneys usually so proportioned that it shall be one-tenth the height.

The batter of the side is about 1 in 40 to 1 in 36.

The thickness of the brickwork at the top, if the internal diameter be equal to or exceed 6 feet, is usually 14 inches for the first 30 feet.

The higher the column the greater will the strength of the brickwork and of the foundation have to be, not only because of the greater weight on each course of brickwork or masonry, but on account of the increase in wind pressure in the higher zones of the atmosphere. This increase in wind pressure increases also the height of the point of application of the effective wind pressure on the whole surface of the chimney.

Suppose P and p be the pressures at the heights H and h, then, according to Stevenson,

$$P = p\sqrt{\frac{H + 72}{h + 27}}.$$

Should the pressure at 50 feet be equal to 40 lbs. per square foot, then the pressure at 100 feet and 200 feet respectively will be 56 lbs. and 86 lbs.

Chimneys are usually built either square on plan, or circular, octagonal, or hexagonal, and the effective wind pressure on the surface of such columns is found to be in the following proportions:—

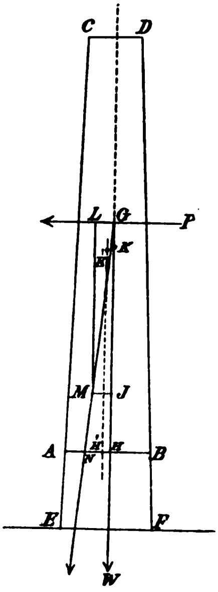


Fig. 181.—Chimney.

If 100 represents the wind pressure on a square chimney, then
75 will represent „ „ hexagonal „
65 „ „ „ octagonal „
and 50 „ „ „ circular „

To find the formula which will enable the dimensions of a chimney to be arrived at, the column C D E F (Fig. 181) must be treated as a cantilever loaded uniformly by the wind pressing with a force of p lbs. on every square foot of the diametral area.

Let h represent the height of the chimney above the bed joint A B, t_o the diametral width of the bed joint A B, and t_t the diametral width at the top C D.

$$\text{The diametral area} = h \times \frac{t_o + t_t}{2}.$$

$$\therefore \quad \text{the total pressure} = h \times \frac{t_o + t_t}{2} \times p = \text{P}.$$

The bending moment about the point N

$$= \text{P} \times \frac{h}{2} = \frac{h^2}{2} \times \frac{t_o + t_t}{2} \times p. \quad . \quad . \quad . \quad . \quad (1)$$

N being the limiting position of the centre of resistance of the joint A B.

In this case P is taken as acting at a point midway between C D and A B, or the centre of pressure is acting at half the height h above A B.

The weight of the chimney = W, and acts through the centre of gravity K of the brickwork above A B, which will be in the centre of the chimney if it is built regularly, and with an equal batter on all sides, and the vertical through K will cut the diametral line A B midway at H.

If, however, the centre of gravity is not in the centre, say at K′, then the weight will pass through a point cutting A B in H′. Let the distance H N be represented by q, and H H′ be represented by $\pm q'$, the sign to be altered according as H′ is on the windward or leeward side of the diameter t_o.

$$\text{Then the moment of stability} = \text{W}(q \pm q')t_o. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For stability, the limiting pressure on the edge B must be *nil*, and must uniformly increase to twice the mean pressure at the edge A.

Then qt_o is found by dividing the moment of inertia I of the cross-sections of A B by the area of the cross-section multiplied by the distance of the point B from the neutral axis $= y_o$.

Let A_o = the area of the cross-section A B.

$$\text{Then } q\,t_o = \frac{\text{I}_o}{\text{A}_o y_o} \text{ and } q = \frac{\text{I}_o}{\text{A}_o m' t_o^2}.$$

Suppose, for example, the cross-section of A B is a hollow square,

$$\text{then } q = \frac{\frac{1}{12}(t_o^4 - t_i^4)}{(t_o^2 - t_i^2)\, m'\, t_o^2}, \ t_i \text{ being the inside diameter.}$$

m' for this section $= \frac{1}{2}$,

$$\therefore q = \frac{1}{6}\frac{t_o^2 + t_i^2}{t_o^2}. \quad \ldots \ldots \quad (3)$$

The moment of resistance, therefore,

$$= \frac{1}{6}\frac{\mathrm{W}(t_o^2 + t_i^2)}{t_o}. \quad \ldots \ldots \quad (4)$$

$$\text{The weight } \mathrm{W} = w \times h \times b \times 4t_a. \quad \ldots \ldots \quad (5)$$

Where w = weight of a cubic foot of masonry (the weight of a cubic foot of brickwork with close joints is about 120 lbs.), and

b = average thickness of the masonry of the chimney, taking the length as four times the average diameter t_a of the chimney above the bed joint A B.

Let B be the average thickness of the actual walling.

$$\text{Then } b = \frac{\mathrm{B}\, t_a - \mathrm{B}^2}{t_a}.$$

Example.—The outside measurement of a square chimney is 18 feet and the walling is 3 feet 6 inches.

$$b = \frac{(3'\,6'' \times 18) - (3{\cdot}6)^2}{18} = 2{\cdot}82 \text{ feet.}$$

This will be found to be correct if the area of the cross-section of the chimney be taken—*e.g.*,

area = 58′ × 3′ 6″ = 203 square feet
= 72′ × 2·82′ = 203 „

Substitute the value of W given in equation (5) in equation (4), we have

$$\mathrm{M}_R = \frac{1}{6} w\, h\, b \times 4t_a \frac{(t_o^2 + t_i^2)}{t_o}. \quad \ldots \ldots \quad (6)$$

The bending moment as found in equation (1) must equal the moment of resistance, equation (6)—*i.e.*,

$$\frac{h^2}{2} \times \frac{t_o + t_t}{2} \times p = \frac{1}{6} w\, h\, b \times 4t_a \frac{(t_o^2 + t_i^2)}{t_o},$$

$$\text{or } p = \frac{8}{3}\frac{w\,.\,b\,.\,t_a(t_o^2 + t_i^2)}{h\,.\,(t_o + t_t)\,t_o} = \frac{4}{3}\frac{w\,.\,b\,.\,(t_o^2 + t_i^2)}{h\,.\,t_o}, \quad (7)$$

$$\text{or } b = \frac{3p \,.\, h \,.\, (t_o + t_i)\, t_o}{8w\, t_a (t_o^2 + t_i^2)} = \frac{3}{4}\; \frac{p \,.\, h \,.\, t_o}{w \,.\, (t_o^2 + t_i^2)} \quad . \quad (8)$$

Rankine gives the value of q as $\frac{1}{3}$ for hollow square chimneys (for hollow round chimneys $q = \frac{1}{4}$), which, if substituted in equations (7) and (8), brings them to a simple form :—

$$p = \frac{8}{3}\, \frac{w\, b\, t_o}{h} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (7a)$$

$$b = \frac{3\, p\, h}{w\, t_o} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (8a)$$

The pressure on the leeward edge of the masonry, as has already been stated, must not be more than $\frac{2W}{A}$, and this must not exceed one-half the crushing strength of the masonry of which the chimney may be constructed. For brickwork and mortar this should not exceed 150 lbs. per square inch.

A graphical construction is shown in Fig. 181. Draw G H vertically through K (the centre of gravity of the chimney above the bed joint A B), and at right angles draw the line P L through the centre of pressure of the wind against the shaft, which will probably be above half the height from A B to C D owing to the pressure being greater at the top of the chimney than it is lower down. Along P L from G mark off with a convenient scale the total pressure of the wind against the shaft, and with the same scale along G H from G mark off G J, the weight of the column above A B; complete the parallelogram L G J M, and draw G M through to cut A B in N. Then N H should equal q.

410. *Foundations.*—In a similar manner, the chimney, if built on a concrete foundation, must not have a greater force on the concrete than one-half to one-third of its crushing strength.

In order to decrease the pressure on the foundations, the footings must be spread out in small offsets, so that the weight is gradually distributed over a large area.

Theoretically, the weight proposed to be put on the surface of any sand, gravel, clay, rock, &c., should not exceed the weight it had before that surface was exposed. This ensures the stability of the foundation, because it does not alter the existing conditions. The conditions are, of course, altered, if it is known that it will allow of a greater weight per square foot than it had prior to its being exposed.

The pressure on any surface should not exceed, according to Rankine,

$$p \overset{=}{<} w x \left\{ \frac{1 + \sin\phi}{1 - \sin\phi} \right\}^2 .$$

Where w = weight of a cubic foot of the earth,
x = depth of the foundation,
p = intensity of pressure per square foot,
ϕ = the angle of slope of the earth.

It is advisable to expose the proposed substratum on which the foundations are to be placed, and, having first calculated the weight of the proposed chimney per square foot, and in the case of buildings including in the weight of the roofs the snow which may be expected to lodge on the roofs, and the vertical wind pressure, place the weight so obtained on a square foot and observe the effect. The measure of settlement should be taken daily. Should there be no settlement after the first day, double the weight, then take further observations; if it remain constant after the first day of such increase of weight, it may be safely used for the buildings.

The safe load, approximately, in tons per square foot on

Quicksand, peat moss, silt, &c., is	0·2
Clay beds of rivers,	0·5 to 1·50
Chalk, soft,	1·0
Damp clay,	1·5 to 2·00
Rock, shaly,	1·75
Chalk, hard,	2·75
Rock and concrete,	3·00
Solid clay with sand,	4·00
Compact gravel,	6·00 to 9·00
Rock, strong,	8·10 to 9·00

Clay and shale, or shaly rock, should never be exposed to the atmosphere, as it crumbles away and may be a source of considerable danger. It should be covered up with concrete or brickwork as soon as possible.

Gravel makes a very good foundation when dry; it is equally good when wet, except for the possibility of the water being at some time drawn away, when it may sink.

If sand is the foundation for a building, the area may be sheet piled in order to prevent the sand from escaping in any manner.

No foundation should be at less depth than that which may be affected by frost, which in England is about 4 feet, but is deeper in some other countries.

411. The compressive strength of Portland cement concrete, mixed in the given proportions of sand and broken stone or gravel, is approximately as follows:—

6 to 1	8 to 1	10 to 1	12 to 1
100 tons.	75 tons.	50 tons.	30 tons.

From rough computations made by the author in actual working, the above proportions are useful in finding the number of tons of cement required in a given number of cubic yards of concrete.

Suppose 100 cubic yards of cement concrete is required in the proportion of 6 to 1, the number of tons of cement is 17 (about). Thus, if x to 1 be the proportion of the concrete, then 1 ton of cement will make x tons of concrete.

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