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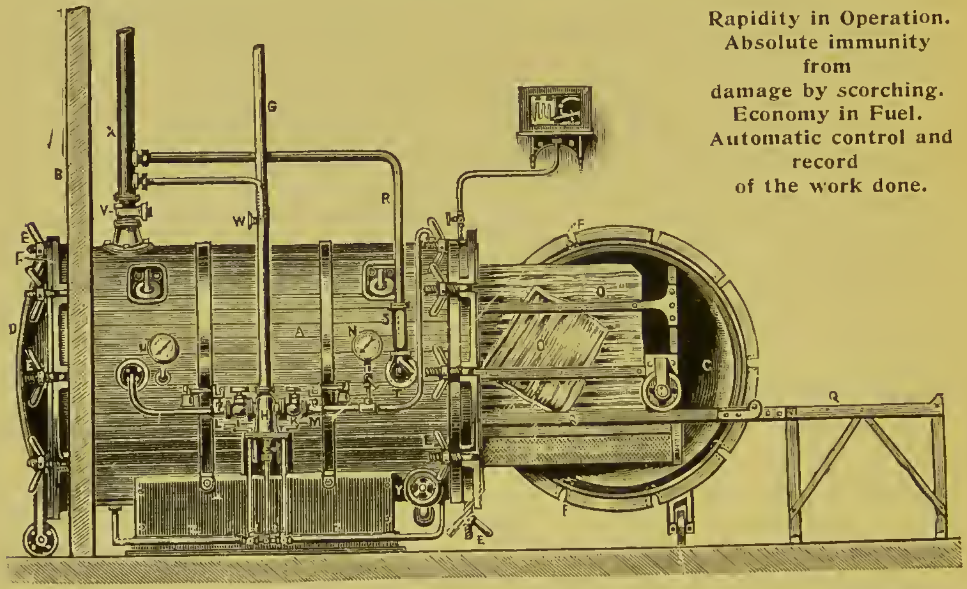

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SEWAGE

AND THE

BACTERIAL PURIFICATION OF SEWAGE

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AND THE

BACTERIAL PURIFICATION OF SEWAGE

BY

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OF ENGLAND

PREFACE

THE rapid development in modern ideas of sewer purification by bacterial processes necessitates a careful review of the methods of sewage disposal at present sanctioned. The important reports published by the London County Council, Manchester, Leeds, and other towns in this country, as well as those of commissions appointed by sanitary authorities in the United States and on the Continent, and the frequent discussions and papers in the technical press, lead me to the view that a *resumé* would be acceptable to a wide class of readers in this country.

The Royal Commission at present engaged on this subject will, no doubt, carefully weigh the evidence which is being placed before it, and we may confidently expect that its conclusions will be in accord with those obtained from the experiments which have now been carried out on sufficiently large a scale to establish the safety of embarking on the treatment of sewage on bacterial lines for even the largest centres of population.

The theoretical basis of the bacterial changes, so far as they have been at present studied, must underlie all the practical schemes which may in the future be put forward, and it has been my endeavour in the following pages to deal with the subject from this point of view.

I have to thank many friends and firms for information and the loan of blocks, and also my assistant, Mr. C. G. Stewart, for helping me in preparing the work for the press.

SAMUEL RIDEAL.

28 Victoria Street,
Westminster,
May, 1900.

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Sewage and the Bacterial Purification of Sewage.

CHAPTER I.

No living being can be healthy while the products of his vital action are allowed to accumulate round him. Even the lower organisms are injuriously affected by the continued presence of their own excreta, so that if they are kept in a confined space, they gradually die off. In the case of higher animals the earliest remedy for such self-poisoning has been migration, but with the increase of numbers the opportunity for this has become more and more limited, and " murrains " and other pests have set in as a consequence of overcrowding. With man there has been the additional burden of the refuse of his industrial occupations.

Sir William Preece's address at Southampton has drawn attention to the injunction of Moses that unclean matters were to be carried outside the camp and burnt, and the necessity of this will be recognized by anyone who has seen in Eastern towns, and even sometimes in British villages, unremoved heaps of decomposing and disease-producing filth.

But the cremation of liquid and solid excreta and vegetable refuse requires much fuel and produces intolerable odours, hence the primitive mode of disposal of effete matters consisted almost entirely in the very effective method which is still in use in dealing with the dead, namely, a committal to earth. Deuteronomy xxiii. 12, 13, enjoins that all excreta shall be covered with earth, following the natural instinct of many animals. It will be noticed that this instinctive effort to cover the dejecta is most prominent in the carnivora, in which the matters are most nitrogenous, and therefore more highly offensive, whereas in the herbivora no such natural propensity is observed.

In the case of pastoral populations depending on springs and wells, water was too scarce and valuable to be purposely polluted. Those residing on the banks of rivers also refrained, to a great extent, from casting their refuse into the streams used for their bathing and drinking, and, having access generally to an ample amount of open and porous soil, employed what we may call the earth system. As soon as a portion of the population, for protection or convenience, became aggregated into settlements, it was early found necessary to set aside certain special places for the reception of refuse, hence the midden heaps that have been widely discovered in the neighbourhood of aboriginal villages. After a time for human excreta ditches or trenches were dug, from which the products of decomposition either sank into the surrounding soil, or found an outlet to some watercourse. In many cases the trenches were at length filled in with earth, over which a rank vegetation grew, and the soil became gradually purified, a plan which is still followed in the case of temporary camps and in Eastern villages. At a later stage, when the progress of civilization necessitated the use, for washing and cooking, of a large quantity of water, isolated inhabitants found it difficult to dispose of the liquids, therefore great pits were dug to receive them, and to keep the rain out were roofed over with beams and earth. At a still later period these excavations were lined with brick, arched over, and connected with the houses by brick or flagstone drains. No cement, as a rule, was used in the construction, as it was found that if the sewage sank into the earth less frequent emptying was required. Moreover, if the receptacle or cesspool were made air and water-tight by cement, it was necessary to provide a vent for the large quantity of gas that was generated in the decompositions. I can record a case where a cemented cesspool in the north of England regurgitated a large quantity of sewage into the cellars of the house, although the pit had been recently erected, and was by no means full. In other cases unventilated cesspools have filled the basement of dwellings with sewer gas.

For houses in isolated positions the cesspool, till lately, was the only available means of sewage disposal, and architects and others spent considerable time and skill upon its design in the early Victorian period, when sanitary progress first drew attention to its importance. I give the following as an example of its successful use, which is interesting on account of its being antecedent both to the French "Automatic Scavenger," to be described in a subsequent chapter, and to the modern "Septic Tank":—

In 1858, a large school in Derbyshire, situate on the top of a lofty hill, surrounded by its own land, but at a distance of two miles from a small river which ran through other property, had to provide for the sewage of 250 to 300 persons, and the drainage from a farm. The water supply was adequate for ordinary needs, but not sufficient for water-carriage of the sewage. A very large cemented brick pit was constructed underground, and arched over, at the back of the buildings and 200 yards from them. Into this the whole sewage passed continuously. When the floating gauge indicated that the pit was full, the whole contents were pumped out from a point near the bottom, and discharged by pipes over cultivated slopes, finally filtering through a gravel and chalk soil into a moderate-sized reservoir in a clayey valley at the foot of the hill, where it mixed with water derived from springs and a rivulet. The mixed water was clear and bright, except for an occasional turbidity from the clay. At the periods of emptying no nuisance occurred; sometimes a faint, earthy odour was noticed when the wind was in the direction.

But in towns, the crowding together of cesspools renders a large area of soil waterlogged with black and fetid matter, which undergoes little or no oxidation; while the periodical clearing out may be an offensive, and sometimes dangerous, process. At Hampstead, for instance, in a sandy soil, cesspools were formerly almost universal, and were thickly distributed, so that the earth, and often the basements, were heavily infiltrated; it is needless to say that most of them have now been removed. A striking example of the pollution of a deep well by leaky cesspools occurred at Liverpool in 1872. The Dudlow Lane well, in the new red sandstone, 443ft. deep, by continuous pumping had dried up all the private wells in the neighbourhood; these were afterwards used as cesspools. As a result, the water in the deep well became polluted, and in a few years after its construction it had to be closed. On diverting the drainage from the cesspools the water was so improved that it was considered safe to resume its use.

In France, and in some places in England, where cesspools are common, they are emptied on the "Pneumatic System." A large barrel is exhausted by an air-pump, and a flexible tube connected with it is passed down into the cesspool. On opening the tap, the liquid is forced up into the barrel without effluvium or exposure to air.

For many reasons it became necessary to organise a regular system of drainage by sewers. But the difficulty was still not overcome. In the ramifications of these canals a good deal of leakage occurred. The construction of traps to intercept the gases, and of ventilators to remove them, was for a long time, and in many parts still continues to be, very imperfect; in fact, the ventilation question is only now showing signs of solution. The greatest difficulty, however, arose when an outlet had to be found for the immense volume of the sewage of modern towns. To discharge it untreated into rivers, unless of many times the capacity of the sewage, and well oxygenated, converted the stream itself into an open sewer. It will be in the memory of many Londoners how black and offensive the Thames was formerly between the bridges, and even in 1894 the Seine near Paris was so polluted that Dr. Billings observed, " Bubbles of gas from the putrefying slime at the bottom escaped from the dark surface, and no fish could live in it," affording an example of a bacterial process working naturally, but imperfectly and under improper conditions. The Irwell, at Manchester, in 1892, was practically sewage, as the following analysis by Hepworth Collins (*Trans. San. Inst.* 1892, p. 196) will show:—Total solids, 160·6; consisting of organic 59·6, mineral 101·0; suspended solids 29·6; ammonia free and albuminoid 0·900; chlorine 11·9; oxygen absorbed 4·90.

But towns and cities are not the only sources of pollution. How far the upper reaches of rivers and streams are contaminated may be judged of by a quotation from a report by the Medical Officer of Health of East Sussex.

> "The filth from farmyards is, as a rule, allowed to gradually soak away in an unpaved and undrained yard, or is washed by repeated rains into the nearest watercourse or pond. Farmers consider it necessary that cattle should thoroughly tread the straw and other litter into liquid manure, in order to render straw more easy to undergo decomposition in the ground. While such process is taking place, the cattle may be seen standing in the liquid filth. If milch cows, the splashing of this water adheres to the udder, and at milking time may easily become mixed with the milk. There is little chance for the beneficent forces of Nature to purify the condition of such a yard, it being a constant swamp. That alternate wetting and drying of the soil so essential for the complete oxidation and renewal of living organisms never takes place. The farmer

> will not listen to the suggestions that stinks and the evaporation of ammonia mean direct monetary loss. The land is deprived of the value of manure as long as it is kept off the fields. It is reasonable to believe what the farmer says: the manure must wait till the land is ready to receive it, or the time is convenient to remove it. Why farmers cannot at once throw the manure into carts and remove it to a corner of the field when it may be required is a mystery. The carts are at times standing idle, and double labour is entailed."

At this point it will be well to classify broadly the various substances that have to be dealt with in the purification of sewage. They may conveniently be arranged under the heads of:

(*a*). *Excretory substances.*

1. Solid fæces. These consist of nitrogenous partially digested matter, together with vegetable non-nitrogenous residues of the food. The former are easily liquefied, but the latter are slow in dissolving, being gradually attacked, chiefly by anaerobic bacteria, and broken down into soluble compounds of fetid odour and into black amorphous flocculi, which slowly deposit as black sludge.

2. Urine. The main source of ammonia, from fermentation of the urea: the proportion of urine being approximately indicated by the content of chlorine in excess of the content of chlorine in the water supply of the town.

(*b*). *Household waste*:—The larger solid substances pass to the ash-pits, but the drainage of these and their washings by rain, if they are uncovered, are received into the sewers together with liquid food-residues discharged down sinks. Vegetable refuse yields a liquid which is very foul and fermenting, developing butyric odours and sulphuretted hydrogen. Fragments of animal food putrefy and furnish a product allied to that from fæces. Diluting these is a fluctuating amount of soap-water, varying at different days and times: its advent is often conspicuous in sewages of small volume through the white opalescence of the effluent, the alkalinity and odour—the latter occasionally indicating scents or disinfectants. Household discharges other than urine may also temporarily raise the amount of chlorine.

(*c*). *Rain and storm-water.*

(*d*). *Grit and detritus.*

(*e*). *Manufacturing waste products.*

The entire refuse will in practice be separated into fractions, which will differ in character according to the size of the community and the system of disposal adopted. In towns the grosser solid matters are collected in ash-bins, which may be fixed or movable, the contents being periodically removed by carts to dust yards. I shall have occasion in Chapter VIII. to refer to the disposal of this portion of the refuse.

Street cleansing is also included in the general processes of scavenging, and results in a semi-fluid mixture, which often constitutes an important feature in the sewage. It contains a complex dust, abraded clothing and wood, castings and emanations of men and animals, and particles of soot, iron, earth and stone, and is usually worse in character, especially from wood pavements, than an average sewage. Samples taken during rain have contained 18 to 30 parts per 100,000 of chlorine, 2 to 3 of albuminoid ammonia in solution, and as much as 80 to 120 of organic solids suspended and dissolved, all of which were formerly swept into the sewers and occasioned serious blocking and deposits. Col. Haywood states that previous to 1877 there were no catch-pits in the city of London except to gullies connected to small pipe-sewers. Now, however, nearly all street gullies are formed with catch-pits, which are emptied at intervals by iron spoons and the contents transferred to mud carts. The chief points to be attended to in these street gullies are:—1. Sufficiency in number and capacity to carry off all surface water. 2. They should not be easily choked by paper, leaves, sticks, or other material entering them. 3. Sufficiency of pit to retain all sand or road detritus to prevent its being washed into the sewers. 4. They should offer the least possible obstruction to traffic. 5. The construction should be adapted to permit the pit being easily cleared out. 6. Effectual trapping to prevent the escape of sewer gas.

The forms adopted have been very various.

Fig. 1 shows a section and plan of a form of gully introduced by Mr. W. N. Blair, the engineer of St. Pancras Vestry, to take the place of some offensive shoots and other gullies which had collapsed.

Fig. 2 gives in section and plan a form of gully constructed largely during the last ten or twelve years at a cost of £11 each. In this case the pit is constructed under the footway and is connected with the gully-grating in the channel by a brick passage, fitted with a flap-trap at its junction with the gully pit, the outlet from the gully pit to the sewer being sometimes trapped at the sewer with a flap-trap; in other cases being untrapped.

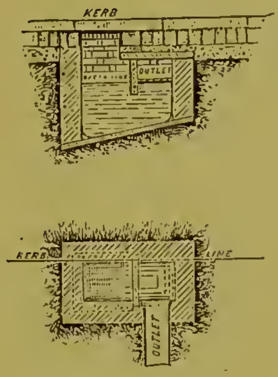
KERB
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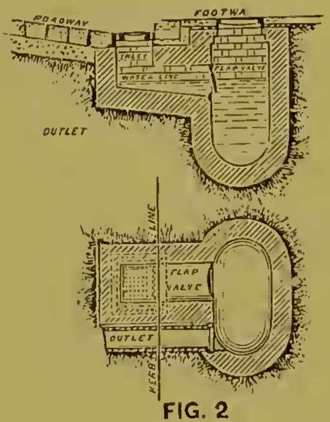
FIG. 1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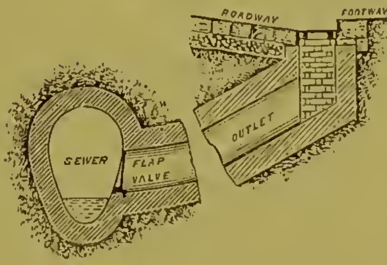
OUTLET

FIG. 2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SEWER
FLAP VALVE

FIG. 3

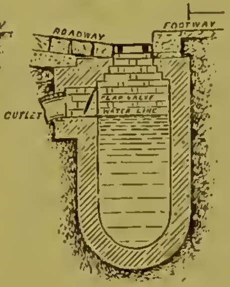
ROADWAY
FOOTWAY
OUTLET
FLAP VALVE
WATER LINE

FIG. 4

Fig. 3. represents a direct shoot from the gully-grating to the sewer ; there are, no doubt, large numbers of this form still existing, in some cases untrapped, in other cases, with flap-traps at either top or bottom, and others again that are trapped at both top and bottom with flap-traps. Other varieties exist in which a pipe shoot is used, which drops vertically from the gully grating, afterwards diverging to the sewer.

Fig. 4 represents a gully pit under the channel of the street, with a grating immediately above it, the discharge being either by a brick shoot or pipe-drain to the sewer. These shoots are usually fitted with a flap-trap in the side of the gully pit. The pits vary from 2ft.6in. in depth to as much as 9ft., and their capacity has sometimes been found to be as much as two van-loads if completely emptied.

It will be seen that of these, Fig. 1 appears to be the best and most sanitary construction suitable for the conditions of traffic of busy thoroughfares.

Crosta's and Sykes' surface water gullies are also good and have the advantage of compactness.

The settlement from all forms of gullies is a wet mud, containing much organic matter, which occasions great difficulty in dealing with town refuse. Therefore, economically, it would seem preferable to rush all sewage down without deposition, except detritus, and treat it collectively at the sewage works.

In some towns human fæces and a certain amount of urine are also removed by scavenging, after being deposited in privies, cesspools, or dry closets.

The methods in which refuse matters are kept for a time, as opposed to those in which they are got rid of as soon as possible by water carriage, are classed together as "conservancy systems." In the country, privies, middens and cesspools were formerly almost universal. Official reports, even up to the present, give striking details of the state of some of our villages and townships in this particular.

In some cases water-carriage is crudely attempted by building the wooden closets over a running stream, which is used by inhabitants for drinking and washing lower down. "Model bye-laws," such that the privy must be a certain distance from dwellings, or from any well, spring or stream, with certain provisos as to construction and cleansing, have been found to be frequently inoperative, as, in the words of a sanitary officer "it is difficult to persuade an owner to spend sufficient money to build a proper privy : he tells you that the property does not pay, and he would prefer to close the houses." Consequently, in settlements built on alluvial ground or porous gravel the soil is frequently saturated with sewage and the wells heavily polluted, resulting at intervals in epidemics, and in a general unhealthy state, especially in the children.

The Local Government Board has laid down "model bye-laws" for the construction of privies and middens in new buildings, prescribing that :—

(1). The privy must be at least 6ft. away from any dwelling.

This distance seems much too short, but is, unfortunately, limited by the amount of ground at disposal, and the convenience of the householders.

(2). That it must be 40 or 50ft. away from any well, spring, or stream.

The object of the regulation is to prevent infiltration into sources of water supply. Here the distance is again inadequate. Although filtration through 40 or 50ft. of porous soil is ordinarily sufficient to remove danger from polluted runnings, recorded cases, such as Maidstone, Hastings, and many I have found in my own analyses, have proved that, owing to the occurrence of cracks, or the formation of channels, specific pollution has been able to traverse a much greater distance. So that observance of the regulation would not attain safety without examination and inspection at intervals.

In the case of Ballard *v.* Tomlinson, 1884, the water in plaintiff's well at a brewery had been polluted and his brewings spoilt by percolation of foul matter " through several yards of chalk " from a disused well which had been turned into a cesspool. Damages were obtained.

Prof. E. Pfuhl has ascertained by direct experiment that certain bacteria could traverse in one hour eight metres (26 feet) of gravel soil, further that the supply of a tube-well became contaminated by B. prodigiosus when cultures of the latter were inserted into the surface 3.7 metres (14 feet) from the top of the well (Zeits. *f.* Hyg., 1897, p. 549). Characteristic bacilli, like prodigiosus and violaceus, have frequently been used with success for testing filters and leakages. Where the suspected source is accessible, a quicker method is to add a quantity of some easily recognizable substance, either in solution or suspension, and to look for it in the water affected. The presence of sewage will also reveal itself in the analysis.

I will give an example that has lately come within my own experience, of an infiltration that passed through a distance of about half-a-mile.

A public school on a hill in the country was supplied with a well-water A, while its sewage was treated on a farm below. Near to the lower extremity of the farm two wells exist, one supplying a swimming bath, therefore not used for drinking purposes, while the other, somewhat more remote, served as a portion of the town supply. The three wells were sunk in the Hythe beds of the Lower Greensand, the direction of the underground water being from the top of the hill to the valley. My analyses of the upper and lower waters were as follows :—

I. CHEMICAL.

	Parts per 100,000.	
	A. Upper Well.	B. Lower Well.
Total solids	29·8	42·0
Chlorine	1·78	2·24
Nitrogen as Nitrate	2·05	2·30
Nitrite	none	faint trace
Free Ammonia	·0046	·0041
Albuminoid Ammonia	·0073	·0109
Oxygen consumed	·013	·019
Phosphate	none	heavy trace
Potassium	almost absent	very distinct

II. BACTERIAL.	Parts per 100,000. A. Upper Well.	Parts per 100,000. B. Lower Well.
Gelatine plates at 22° C ...	127 colonies ...	454 colonies
Agar plates at 37·5° C ...	no colonies ...	135 ,,
Carbolic Agar...	,, ...	5 ,,
Broth tube	clear : no indol ...	turbid : strong indol reaction

proving distinctly the access of pollution from the sewage farm.

(3). Means of access must be provided for the scavenger, so that the filth need not be carried through a dwelling.

The rule is to a great extent aimed at the evil of "back-to-back" houses, a large number of which still exist in some localities.

(4). The privy must be roofed to keep out rain, and provided with ventilating openings as near the top as practicable ; that part of the floor of the privy which is not under the seat, must be not less than 6 inches above the level of the adjoining ground, must be flagged or paved with hard tiles, and must have an inclination towards the door of the privy of ½ inch to the foot.

I have observed that a properly laid cement floor is far preferable, as the spaces between tiles or flags, and the unevenness resulting from wear, render them difficult to keep clean and to repair.

(5). The next regulation is intended to prevent the accumulations of filth in large pits that are still frequently found behind rows of cottages, and to secure at least a weekly removal.

"The capacity of the receptacle under the seat of the privy must not exceed 8 cubic feet (50 gallons), the floor of this receptacle must be in every part at least 3 inches above the level of the adjoining ground ; its sides and floor must be made of impermeable material—they may be flagged or asphalted, or constructed of 9-inch brickwork rendered in cement : the seat may be hinged, or other means of access to the contents of the receptacle must be provided ; and the receptacle must not communicate with any drain or sewer."

The chief utility of such regulations is to secure regular inspection and the power of using compulsory measures on definite lines where necessary. Anyone who is acquainted with country places even up to the present date knows that almost all middens and privies are constantly offensive, especially in hot weather : the fact that the residents, from habit, do not notice the nuisance does not prevent it from being injurious to health. The judicious use of a sprinkling of dry cinders or ashes avoids to a certain extent the offensiveness.

The Pail System. In Rochdale and some northern towns, the excreta are collected in iron or tarred-oak pails of a capacity of under 2 cubic feet, and provided with lids. They are placed under the seat of the closet, which should be well ventilated ; the contents are covered with cinders or ashes and removed at least once a week, a clean pail being substituted.

An important point is that the contents should be kept as dry as possible, and that if it is designed to convert the matter afterwards into manure, nothing but the excreta and a minimum of ashes should be thrown into the pail

In some villages, and in many continental towns the pail system is carried out in a much less careful manner, the pails being collected at night-time, and the contents—hence called " night-soil "—with or without a perfunctory disinfection, emptied into ditches or pits, which when full are covered up with earth.

With the object of saving the manure, as well as immediately disinfecting the fæces, Moule in 1863 introduced the system of Earth Closets, a kind of resuscitation of the primitive earth-disposal that we have already noticed. By a mechanical arrangement similar to that of a water closet, on pulling a handle each discharge of fæces was covered by a shovelful, about 1½lbs., of dry earth. This was baked daily in an oven, and issued to the households. Its absorbent character instantly removed all odour when only a light covering was spread over the solid discharge. The final effect was a bacterial one, by which paper and solid fæces were soon reduced to a loamy powder which could be dried and used again several times. Two reasons, however, militated against success :—

(1). Urine or other moisture ruined the absorbent effect unless a large quantity of earth was used.

(2). Owing to the rapid loss of nitrogen and the admixture of earth, the manure was of little value, containing only about a tenth per cent. of nitrogen, and ½ per cent. of phosphoric acid.

The process is rather a deodorizing than a disinfecting one, as pathogenic organisms are not killed, but for places without a copious water supply, this system has great advantages, and is much superior to privies. Dr. Vivian Poore, in his garden at Andover, has elaborated this idea and shown that it can be worked effectively without nuisance and with very satisfactory crops. The kind of earth is a matter of importance—sand and gravel are inert, chalk feeble and dry clay good, while garden soil, loam, and peat give the best results. In public urinals without a water supply sawdust can be substituted for earth.

The Goux-Thulasne method, called shortly "the Goux," is used frequently on the continent, and has been worked successfully at Halifax in England. It is a combination of the earth and pail systems. In an iron barrel with handles a slightly conical core is held, and the intervening space packed with dry earth, or a pulverulent disinfectant. When the core is withdrawn, a cavity of the same shape is left. These receptacles are carried round on a dray, and left at the houses. At the end of a few days they are collected, shaken so as to cover the excreta with powder, and covered with an air-tight iron lid before removal. Success here again depends on the exclusion as far as possible of moisture. This is a useful method for sick rooms when the excreta must remain for some time.

Places in which "conservancy systems" are in practice are classed together as "midden towns." Their sewage excludes a great part of the human excreta, and is made up of :—

(*a*). Waste water from kitchens, highly charged with decomposable matters and grease ;

(*b*). Slop water, containing urine, soap, and the dirt from the surface of the body and from clothes ;

(*c*). Liquid refuse and drainage from stables, cowsheds, piggeries, and slaughterhouses (the drainage from stables is very rich in urine : one horse excretes about fifteen times as much urine as an adult man) ;

(*d*). Street washings and sweepings ;

(*e*). Urine and water from public urinals, and usually from a few water closets ;

(*f*). Waste liquors from factories.

(*g*). Drainage of land, rain and storm water, except where the "separate system" of sewage, which excludes these, is adopted.

The average figures for the sewage for midden and water closet towns, as given by the Rivers Pollution Commissioners, shows no very conspicuous difference in composition, while according to Sir E. Frankland, in earth-closet localities a similar uniformity was observed.

Parts per 100,000.

	Solids.	Cl.	Org. C.	Org. N.	NH_3	Total Combined N.	Suspended Matter.		
							Mineral	Org.	Total.
Midden Towns	82·4	11.54	4.18	2·97	5·43	6·45	17·8	21·3	39·1
Water-closet Towns	72·2	10·66	4·70	2·20	6·70	7·73	24·2	20·5	44·7

The inclusion of solid excreta in the water-closet towns is balanced by the water used for their carriage, the result being that the two sewages are practically equal as regards subsequent disposal.

The majority of towns have now adopted water-carriage for the disposal of fæcal matters. The chief objection that has been urged against this method is the waste of the water supply. But the amount of water used per day in closets not being measured by meter, has often been over-estimated. If we take the chlorine figures in the above analyses as an approximate measure of the strength of the sewage—a mode of estimation that I will explain in the second chapter—we find their ratio to be 11.54 to 10.66, or nearly 11 to 10, that is to say, an addition of one-tenth to the ordinary water supply has been sufficient to replace the carts and other apparatus, besides the labour, of the pail, earth and other conservancy systems.

Another method of arriving at the amount used is by the volume of flush. Putting this at two gallons, and assuming two uses per day per individual, we reach a figure of four gallons, or from $\frac{1}{8}$ to $\frac{1}{10}$ of the water supply per head. So that the volume of sewage will not be greatly increased, and its dilution will not be detrimental in subsequent bacterial treatment, as we shall see in the tenth chapter.

It may be concluded that wherever an adequate supply of water is attainable the water carriage system is the best. Dr. Louis Parkes* sums up the comparison of methods so clearly that I may quote his words.

> "There can be no doubt that all conservancy systems proceed on a wrong principle, namely, that of keeping excremental matters within or near dwellings as long as they are not considered to be a nuisance or dangerous to health. In towns the expense of scavenging is directly proportional to the frequency of removal, so that there is always an inducement to the local authority to economize at the risk of the health of the inhabitants. The costs of this kind of scavenging are high—in many towns very high—and in but very few does the sale of the refuse cover the expense.
>
> That improved middens and pail or earth closets are a great advance upon the former disgraceful conditions which prevailed in most towns nobody will deny; but it is difficult to justify the existence of any such systems when all the facts are known . . . . The pail system is undoubtedly the best for towns which will not enforce the adoption of water closets. Sanitarily considered it is inferior to the earth system, in which dryness of the excrement, by the addition of dry earth, is part of the system. But however

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* *Hygiene*, 1897, p. 116.

suitable for country houses, and for villages in this country, and for villages and stations in India, where earth of suitable quality is easily procured and dried, and the compost can be distributed over gardens and fields in the immediate vicinity, it is quite inapplicable to towns of any size on account of the enormous quantities of earth that would have to be dried and brought into the town, the difficulties of storing the earth on the premises of houses and keeping it dry, and the still larger quantity of useless manure to be removed out of the town and further disposed of."

We have already alluded to the ultimate disposal of sewage by dilution, that is by the discharge into large natural bodies of water. We shall now have to further consider the

EFFECTS OF DILUTION.

With conditions that are favourable, the purifying action of rivers is known to be very great. Towns on the banks of rivers of considerable width, and having a fairly constant volume and velocity during all seasons have discharged their raw sewage into the stream for many years, and investigation has proved that a few miles below the outlet of the sewers there is little or no trace of pollution.

Many chemists believed that sedimentation was the main cause of any self-purification in river water. But any extensive improvement by mere sedimentation would be on the wrong lines, and should not be permitted, as it would result in a filling up of the river bed and formation of dirt banks which become foul. If, on the other hand, suspended organic matter is slowly removed to the river bed and there is attacked, in the absence of air and light, by the organisms naturally fitted to the purpose, their products will dissolve and become available for the water bacteria in the river. In a paper read at the British Association at Bristol in 1898 on " Standards of Purity for Sewage Effluents," I discussed the conditions for safe discharge into a flowing stream, pointing out that " methods had been found which, by natural agencies, allowed us to carry the purification to a rational and harmless stage, when such factors as time, light, volume of oxygen, and various life of a river will be more than sufficient to deal with the effluent."

Pettenkofer, from investigations on the river Isar, at Munich, has concluded that if the sewage never amounts to more than 1-15th, or 6.7 per cent. of the river water, and the velocity of the latter is at least equal to that of the former, the raw sewage may be poured into the river without causing pollution.

In America, from the results of actual observations on rivers, under the direction of the Massachusetts Board of Health, Rudolph Hering fixes a limit to the amount of free ammonia permissible in a stream, and finds that if the flow of a stream is less than 2½ cubic feet per second per 1,000 persons (or one gallon per minute per person), " an offence is almost sure to arise," but when the flow is greater than 7 cubic feet per second per 1,000 persons then safety is assured. " In other words, when the free ammonia is greater than 0.12 parts per 100,000, the conditions are probably objectionable." These limits correspond to about 50 volumes of river water to average sewage in this country. Mr. Stearns, the engineer to the Massachusetts Board, concludes that if the average amounts to more than 1-40th, or 2·5 per cent. of the river water, it cannot be discharged into the river in its raw state ; if it amounts to less than 1-40th, and more than 1-130th, it is doubtful ; if less than 1-130th, it may be admitted without any doubt in its raw state into the river. These conclusions are, of course, empirical, and have not been generally accepted ; they would be greatly affected by the amount of solid matter present in the discharge. It must be remembered that the sewage in America is much more dilute than in this country, that the rivers have greater volume, and that the limit is much higher than we have found necessary in England.

It is possible, however, to form an estimate as to the amount of sewage which can be dealt with by a flowing stream, if one remembers that the bacteria, always naturally abundant in river water, are able by the aid of the oxygen dissolved from the air to oxidize more or less rapidly any ammonia or organic matter, that may be present. That the volume of the sewage and the oxygen required by the organic matter in it as measured by permanganate—*i.e.*, the standard factor of " oxygen consumed "—should bear some relation to the free dissolved oxygen in the river, and the flow of the river, is obvious. But, in addition to this, it is also desirable to take into account the amount of available oxygen as nitrate and nitrite, since it has been proved that, always with the help of bacteria, the oxygen of nitrates and nitrites is available for the burning up of organic matter.

From these factors the following formulæ may be deduced. Where X is the flow of the stream, O the amount of dissolved oxygen, S the volume of effluent, M the " oxygen consumed " by the latter, N the available oxygen as nitrate and nitrite, C the ratio between the amount of oxygen in the stream and that which is required to oxidize the organic matter in the effluent, then the equivalent will be—

$$XO = C(M - N)S,$$

where the sewage is fresh, and no nitrates have been formed

$$XO = CMS.$$

If N be less than M, $M - N =$ the deficit of oxygen in the effluent, requiring to be supplemented by the free oxygen in the river: such an effluent will throw a burden on the river, and cannot be considered in a satisfactory state, and it will be a question of volume and other circumstances whether it can be permitted to be discharged at all. This may be determined by the consideration that if the available oxygen of the river, XO, be greater than the demand $(M - N) S$, there will be a chance of the stream dealing with the inflowing liquid, but if the reverse be the case, foulness will necessarily accrue.

In the favourable cases where bacteria and algæ are active, and the oxygen of the river is able, by their help, to deal rapidly with the incoming residues, the minimum ratio between the volume of the stream and the volume of effluent that could be allowed to be discharged into it would be indicated by the value of C in the above equation, which would also approximately denote how far the population might increase before the proportion could be seriously disturbed. The minimum figure will be reduced by the nitrites or nitrates of the river water itself, or the free oxygen which may be present in the effluent. River water often contains about 90 per cent. of its nitrogen in the oxidized form, and when saturated, holds about 700 c.c., or, approximately, one gramme of dissolved free oxygen per 100 litres. These materials for purification require to be supplemented by the agency of the natural bacteria, which, with the almost unlimited expose and admixture in a flowing river, we may assume as certain to be present. Hence, in theory, comparatively few volumes of a river water will supply the requisite oxygen, which explains the well-known fact that in the lower reaches of a river the dissolved impurity is only a fraction of what has entered in its upper course. Dupré states that, on an average, dilution with thirty volumes of fully aerated river water prevents sewage from fouling, and ultimately purifies it. Even a less proportion, in my experience, has been effectual.

For one town then, on the banks of a large river, or even several towns, if they are sufficiently separated to allow natural recovery and aeration of the stream, the elementary method of discharging the untreated sewage into the water direct has been successful in the past, with the proviso usually required that by screening, sedimentation or precipitation, the suspended solids should be prevented from forming mud-banks and deposits of black sludge on the river bed.

Exeter, for example, a town which is now interesting from its association with the septic tank system, has also the historical position of being the first city to be sewered, and to discharge the combined sewage, untreated, into a river. As the volume of the Exe is about forty times that of the sewage, at the recent inquiries no chemical evidence of pollution a few miles below the city was obtainable.

Composition of River Exe, 1894.

	T.S	Cl.	NH_3	Alb. NH_3	Oxygen absorbed.
Above Exe Bridge ...	9·1	1·19	·007	·016	·29
Below the Town at Trew's Weir ...	10·85	1·22	·025	·023	·30

But in countries thickly populated there is no such opportunity for the recovery of the river. Given even twenty-four hours for the completion of the natural process, the river would arrive at the next town denuded of its oxygen and in an unfit state for the reception of more sewage. The result has been such a condition as I have already mentioned in connection with the Seine and Irwell. Hence it is, as a rule, necessary for the sewage to be prepared before it can be allowed to be discharged, and the methods for so doing constitute our present subject.

There can be no doubt that on the efficiency with which refuse matters, and especially human excretal refuse, are removed from towns, their health largely depends.

The improvement in the health of towns as shown by the reduction in the death rates coincide with the completion of works of sewage, and the introduction of a better water supply. Sir William Preece in an address to the National Health Society, October, 1899, referred to the city of Leeds, with a population of 400,000, where during the twenty years 1875-1895 the death rate per 1,000 fell from 28 to 18, and continued "if this had been accomplished in one city by acting on those principles of applied science, what might be the total number of lives saved throughout the country by the operation of those whose duty it was to carry out the details of the science of sanitation? It had been said that 'a nation's health was a nation's wealth,' and there was no doubt that the strength of a nation depended more on the health of its population than on anything else."

CHAPTER II.

Chemical Analysis of Sewage and Effluents—Methods of Collecting Samples—Gauging the Flow—Samples should be Collected proportional to the Flow and corresponding to one another—Weirs—Floats—V Notch—Meters—Hourly Variation of Sewage—Official Methods of Collection and Analysis—Recommendations of the British Association—Determinations of Total Solids—Chlorine—Free and Albuminoid Ammonia—Oxygen Consumed—Mineral Constituents.

SAMPLES for analysis should be taken proportionately to the flow, and not in equal quantities as is often done, notably in recent experiments at Manchester. The method of working that I have adopted as the best in sewage investigations is as follows :—

A sample is collected and a gauging done every hour, or, if possible, every half-hour. The gauging of the flow is attained by one of the standard systems, which are described in books on Hydraulics. The usual method is to make the fluid pass over a sharp-edged horizontal weir, and to measure the depth of liquid flowing over the weir in inches, by means of a post placed behind it. By Hawksley's formula, if h = this depth, l the length of the weir in feet ; then Q, the flow in gallons per second, will be obtained by

$$Q = \frac{l\,h\,\sqrt{h}}{2}$$

From these data tables are calculated giving the flow in gallons corresponding to decimals of an inch.

A practical difficulty in measuring the volume of raw sewage is that weirs or constrictions of any kind cause an obstruction to the flow, and, therefore, clogging or deposits.

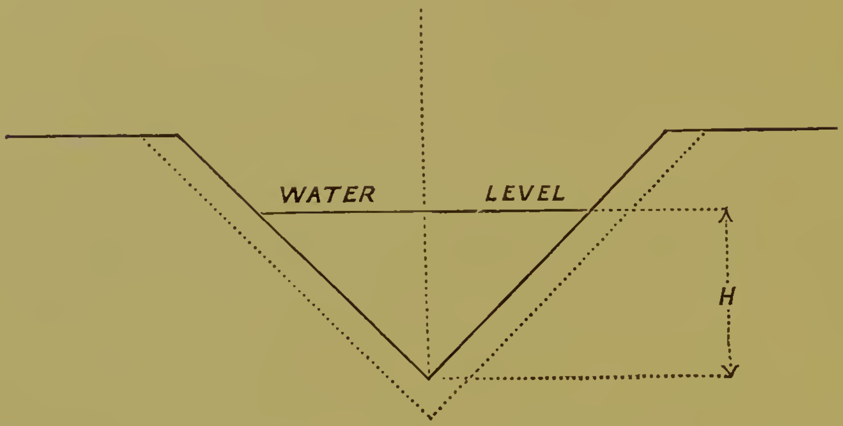
But where the channel admits of access at several points, an estimate of the discharge can be obtained without retardation by the float method. A piece of wood is released at one point and the time required for its appearance at another point is registered ; the distance being known, the surface velocity of the stream is ascertained in feet per second. As the surface velocity in the centre of a current is greater than the mean velocity of the whole, a correction must be made. A nearer approach to the average can be attained by using as the traveller a tube made to float vertically by weighting at the bottom. A good float of this kind can be made from a piece of glass combustion tubing closed at the lower end and weighted with shot or mercury, so as to sink about three-quarters of its depth, the upper end carrying a white or red flag to make it conspicuous. Several preliminary trials should be made as to the length of tube that can pass without obstruction, and in some cases a string may be attached for recovery, with care to avoid error. A number of formula have been proposed for calculating the mean velocity from the surface velocity, and will be found in engineering books, suffice it to say that the volume of discharge is calculated by multiplying the mean sectional area of the channel (found by measuring at several parts) by the mean velocity in feet per second. An example of the calculation will be useful.

In a culvert with several manholes a float, immersed to the depth of six inches, was observed to traverse 25ft. in 100 seconds, = 0·25 feet per second. This was taken as the mean velocity of the stream. The mean area of the channel by measuring the depth and width of the liquid was found to be 3 square feet. Then $3 \times 0{\cdot}25 = 0{\cdot}75$ cubic feet per second. A cubic foot of water is 6¼ gallons. The flow therefore is at the rate of 64,800 cubic feet, or 405,000 gallons, in 24 hours.

It is often convenient to measure the time in seconds required to discharge a certain number of gallons into a pail or zinc bath of known capacity, a method which dispenses with formulas, and is quite accurate where applicable. In a recent instance the gauging made in this way was corroborated subsequently by a proof of the flow from official sources. Thus my average gauging by the pail was 15,886 gallons per 24 hours, the official figures afterwards received were 15,571.

A simple rule to remember is that cubic feet per minute × 9000 = gallons per 24 hours.

An effluent is easier to measure on account of the absence of solid matter. It may be made, as at Exeter, to flow through a V notch at an angle of 90° in the side of a tank. The area of the orifice will be half the square of the *side* from the vertex to the water level. The amount of the efflux can be calculated, or may be determined experimentally and tables prepared giving volumes of flow corresponding to the level of liquid in eighths of an inch. The actual V notch should be a thin plate of zinc or thickly galvanized iron ; or, if of wood, it must be sawn to a clean bevel, with the sharp edge up stream.



The V or the right-angled isosceles notch was originally suggested by the late Prof. James Thomson, of Glasgow, and has been adopted by the Septic Tank Syndicate in their installations for measuring the flow from the tank. The advantage of a V over a square notch or weir is that, however small the flow of water with the V notch, there is always a readable quantity. The variation in the area of water flowing in a V notch is as the square of the height from the vertex, and the volume discharged as the $\frac{5}{2}$ power of that height.

The formula is

$$Q = \cdot 305 \, H^{\frac{5}{2}}$$

Where Q = cubic feet per minute and H the height in inches from the vertex of the notch up to still-water level. Prof. Thomson found that when H = 12 inches the flow was 2·54 cubic feet per second. So that by measuring H in feet and taking this figure to the $\frac{5}{2}$ power, and multiplying by 2·54 you get the flow in cubic feet per second.

In those cases in which a permanent record of the flow is required, it is more convenient to use a Parkinson's low pressure water meter which, if read at fixed intervals, will give the quantity of sewage dealt with.

Samples of effluents should be taken comparable to the raw sewage. This is sometimes difficult, as the time of passage through the tanks or filters is not accurately known. The capacities of the beds and tanks and the flow at the time of sampling will, in most cases, give the necessary data, but even

FLOW OF WATER IN THE RIGHT-ANGLED V NOTCH.

Height, Inches	Quantity Cubic Feet per Minute.	Height, Inches.	Quantity, Cubic Feet per Minute.	Height, Inches.	Quantity, Cubic Feet per Minute.	Height, Inches.	Quantity, Cubic Feet per Minute.	Height, Inches.	Quantity, Cubic Feet per Minute.	Height, Inches.	Quantity, Cubic Feet per Minute
		5·125	18·13	10·125	99·5	15·125	271·1	20·125	554	25.5	1001·5
·25	·0095	·25	19·26	·25	102·6	·25	277·0	.25	563	26	1051
·375	·0263	·375	20·43	·375	105·7	·375	282·5	·375	571	27	1155
·50	·054	·50	21·64	·50	109·0	·50	288·5	50	580	28	1265
·625	·094	·625	22·89	·625	112·2	.625	294·1	·625	589	29	1381
·75	·143	·75	24·18	·75	115·6	.75	300·3	·75	598	30	1504
·875	·218	·875	25·52	·875	118·8	·875	306·5	·875	607	31	1632
1·00	305	6·00	26·89	11·00	122·4	16·00	312·0	21·00	616	32	1767
1·125	409	·125	28·33	·125	125·8	·125	318·7	·125	626	33	1908
1·25	·533	·25	29·79	·25	129·5	·25	324·7	·25	635	34	2056
1·375	·676	·375	31·29	.375	133·1	·375	331·2	·375	644	35	2210
1·5	·840	·50	32·85	.50	136·8	·50	337·3	·50	654	36	2372
1·625	1·027	·625	34·46	·625	140·4	·625	344·4	·625	663	37	2540
1·75	1·23	·75	36·10	·75	144·4	·75	350·2	·75	673	38	2715
1·875	1·43	·875	37·80	·875	148·1	·875	357·0	·875	682	39	2897
2·00	1·73	7·00	39·54	12·00	152·1	17·00	363·4	22·00	692	40	3086
2·125	2·01	·125	41·33	·125	156·0	·125	370·1	·125	702	41	3283
2·25	2·32	·25	43·17	·25	160·2	·25	376·9	·25	712	42	3487
2·375	2·66	·375	45·05	·375	164·2	·375	384·1	·375	722	43	3698
2·5	3·01	·50	46·98	·50	168·5	·50	390·8	·50	732	44	3917
2·625	3·41	·625	48·97	·625	172·6	·625	397	·625	743	45	4143
2·75	3·82	·75	51·0	·75	177·0	·75	404·9	·75	753	46	4377
2·875	4·27	·875	53·1	·875	181·2	·875	412·0	·875	763	47	4619
3·00	4·75	8·00	55·2	13·00	185·8	18·00	419·0	23·00	774	48	4869
3·125	5·27	·125	57·4	·125	190·1	·125	427	·125	784	50	5092
3·25	5·81	·25	59·6	·25	194·9	·25	434	·25	795	52	5947
3·375	6·38	375	61·9	·375	199·3	·375	442	·375	806	54	6536
3·5	6·99	·50	64·2	·50	204·2	.50	449	·50	817	56	7158
3·625	7·63	·625	66·6	·625	208·8	·625	457	·625	827	58	7814
3·75	8·30	·75	69·1	·75	213·8	·75	464	·75	838	60	8505
3·875	9·11	·875	71·6	·875	218·8	·875	472	·875	849	62	9231
4·00	9·76	9·00	74·1	14·00	223·7	19·00	480	24·00	861	64	9994
4·125	10·54	·125	76·1	·125	228·5	·125	488	·125	872	66	10793
4·25	11·35	·25	79·4	·25	233·8	·25	496	·25	883	68	11630
4·375	12·21	·375	82·1	·375	238·8	·375	504	·375	895	70	12494
4·50	13·10	·50	84·8	·50	244·2	·50	512	·50	907	72	13416
4·625	14·03	·625	87·7	·625	249·5	·625	520	·625	918	75	14858
4·75	14·99	·75	90·5	·75	254·8	·75	529	·75	929	78	16392
4·875	16·00	·875	93·5	·875	260·1	·875	537	·875	941	80	17419
5·00	17·05	10·0	96·4	15·00	265·8	20·00	546	25·00	953	81	18010
								·25	977	84	19724
										87	21533
										90	23437
										96	27541
										100	30500

then allowance must be made for streaming. I have found the only accurate way is to spread the sampling over successive days, choosing different times each day until the cycle of twenty-four hours is complete. On small systems, discharges from swimming baths or manufactories at uncertain periods are apt to give considerable trouble in obtaining average samples.

Collection of Samples.

It is necessary that these should be taken in a representative manner, and considerable labour and attention must be devoted. A great many published analyses are based on specimens taken casually, and the opinions formed are of little or no value. The sewage is continually flowing, but varies both in volume and quality from hour to hour. I will quote a table of my own analysis of a town sewage illustrating this point, and also showing the different effects of dry and of wet weather.

Parts per 100,000.

Time and Circumstances.	Flow in gallons per 24 hours.	Solids in Solution.	Cl.	O consumed	Free NH_3	Albd. NH_3	Nitric N.	Nitrous N.
Dry weather, no rain.								
10 a.m. to 5 p.m. -	54,000	77·5	12·25	7·23	8·0	1·5	None.	None.
6 p.m. to 1 a.m. -		45·0	6·25	6·91	2·90	0.6	,,	,,
2 a.m. to 9 a.m. -		34·0	4·25	5·57	0·90	0.35	,,	,,
	Total Chlorine—41 lbs. per day.							
Heavy storm.								
10 a.m. to 5 p.m. -	79,000	54·4	7·75	3·58	11·5	4·12	·056	None.
6 p.m. to 1 a.m. -		45·6	5.25	2·66	3·5	1·75	·014	Trace.
2 a.m. to 9 a.m. -		34·4	3·75	0·74	4·5	5·5	Trace	Very heavy.
	Total Chlorine—44 lbs. per day.							

Physical Characters.—Dry weather: Thick and fetid, fragments of paper and lumps of fæcal matter abundant.
,, ,, Heavy storm: Turbid, yellow-brown, earthy odour.

In the morning, urine is prominent, as shown by the chloride and by other signs; later on, soapy water makes its appearance, with a white scum of fatty lime-salts that tends to clog filters and leave a greasy deposit on channels; fixed alkalinity also appears, with an increase in the sodium salts; subsequently the sulphuretted odour of vegetable washings is evident, and the liquid may even become temporarily acid. The road detritus and heavier matters are usually caught in a grit chamber, while paper, string, and animal and vegetable fragments are commonly carried forward with the mixture, which rapidly becomes black, alkaline, and putrescent. The following analyses show the alteration occasioned by mere mechanical straining or filtration. They are averages of thirteen hourly samples from 6 a.m. to 6 p.m. taken from different sewers of a large town on the water closet system in 1897.

TABLE SHOWING VARIATION IN QUALITY OF SEWAGE IN DIFFERENT SEWERS OF THE SAME TOWN.

Parts per 100,000	Organic N.	Solids.	Cl.	Free NH_3	Alb. NH_3	O consumed.	Nitric N.	Nitrous N.
A.—Dissolved - -	7·21	94·0	20·8	6·5	3·1	5·34	·096	None.
Suspended - -	6·18	35				5·86		
Total - -	13·39	129				11·2		
B.—Dissolved - -	5·56	57	11·1	5·0	1·6	5·86	·12	None.
Suspended - -	3·71	51				9·38		
Total - -	9·27	108				15·24		
C.—Dissolved - -	7·2	72	12·7	7·0	3·65	6·59	·08	None.
Suspended - -	1·55	60				7·68		
Total - -	8·75	132				14·27		
D.—Dissolved - -	11·33	90	12·0	7·0	2·05	8·67	·12	None.
Suspended - -	1·85	45				5·28		
Total - -	13·18	135				13·95		
E.—Dissolved - -		66	10·4	5·5	1·53	5·41	·14	None.
Suspended - -		33				3·39		
Total - -	11·12	99				8·80		
Average—Dissolved -	7·82	76	13·4	6·2	2·39	6·37	·11	
Suspended -	3·32	45				6·32		
Total - -	11·14	121				12·69		

These examples show that the suspended solids contain about one-third of the organic nitrogen and half the carbonaceous matter of the sewage.

Anyone who has observed the outflow of raw sewage will know that it is hopeless to take a fair average sample in a bottle, owing to the large pieces of solid matter that at intervals come down. The only thing to be done is to roughly strain the sample for analysis, and to ascertain on a larger scale the amount and nature of the solids.

Opinions on sewages and effluents must be based on a number of examinations extending over several days and embracing every hour of the day. At the same time opportunity must be given for immediate analyses simultaneously, as delay produces change. I will give an example of the procedure by which I attained this in October, 1899. A strong sewage was gauged every half-hour, and a sample collected in cubic centimetres proportional to the number of gallons flowing: these half-hourly samples were at once poured into a large vessel, and at the end of three hours were thoroughly mixed and the average of the six samples taken in a stoppered glass bottle for analysis. The results and the times are given in the table, and it will be seen that they include each hour of the 24, taken twice, extending over 7 days. The periodic fluctuations that I have mentioned, are also shown.

Parts per 100,000.

Time.		Chlorine.	N as NH_3	Total Nitrogen.	Oxygen Consumed	Gallons discharg'd in the 3 hours.
Monday	9—12 a.m.	15.0	22·7	34·6	34·1	4358
,,	3—6 p.m.	16·0	11·5	13·2	20·7	1491
Tuesday	6—9 a.m.	15·6	26·3	33·0	20·8	5450
,,	12—3 p.m.	19·4	11·5	14·8	16·6	1762
Wednesday	3—6 a.m.	6·4	7·7	10·0	3·5	434
,,	9 a.m.—12 noon	12·4	8·4	12·4	16·2	2529
Thursday	midn.—3 a.m.	4·5	2·2	3·4	9·6	1904
,,	6—9 a.m.	9·5	9·7	13·4	10·2	6690
,,	9 p.m.—midn.	11·1	10·4	12·5	7·8	1054
Friday	3—6 a.m.	3·8	2·1	2·9	1·2	432
,,	6—9 p.m.	19·6	17·8	24·6	18·7	888
Saturday	midn.—3 a.m.	23·5	18·0	22·3	10·3	563
,,	3—6 p.m.	12·4	10·4	12·4	24·8	1751
,,	9 p.m.—midn.	24·8	18·5	26·3	21·2	614
Sunday	noon—3 p.m.	23·3	16·6	18·2	12·2	1535
,,	6—9 p.m.	24·1	17·4	21·5	11·1	678

Nitrites and nitrates were only present in traces.

It has long been seen that it was desirable that a uniform method should be agreed on for collecting samples, conducting analyses and recording results, in order that comparative figures should be obtained.

A British Association Committee was appointed in 1898 to suggest some uniform method of recording results, and after having had the advantage of considering the special reports of the Royal Commission on Sewage Disposal, recommended in 1899 as follows:—

"That it is desirable that results of analysis should be expressed in parts per 100,000, except in the case of dissolved gases, when these should be stated as cubic centimetres of gas at 0°C. and 760 mm. in 1 litre of water. This method of recording results is in accordance with that suggested by the Committee appointed in 1887 to confer with the Committee of the American Association for the Advancement of Science, with a view to forming a uniform system of recording the results of water analysis*."

2. The Committee suggest that in the case of all nitrogen compounds the results be expressed as parts of nitrogen over 100,000, including the ammonia expelled on boiling with alkaline permanganate, which should be termed albuminoid nitrogen. The nitrogen will, therefore, be returned as—

(1) Ammoniacal nitrogen from free and saline ammonia.
(2) Nitrous nitrogen from nitrites.
(3) Nitric nitrogen from nitrates.
(4) Organic nitrogen (either by Kjeldahl or by combustion, but the process used should be stated).
(5) Albuminoid nitrogen.

The total nitrogen of all kinds will be the sum of the first four determinations.

The Committee are of opinion that the percentage of nitrogen oxidized, that is, the ratio of (2) and (3) to (1) and (4) gives sometimes a useful measure of the stage of purification of a particular sample. The purification effected by a process will be measured by the amount of oxidized nitrogen as compared with the total amount of nitrogen existing in the crude sewage.

In raw sewage and in effluents containing suspended matter it is also desirable to determine how much of the organic nitrogen is present in the suspended matter.

In sampling, the Committee suggest that the bottles should be filled nearly completely with the liquid, only a small air bubble being allowed to remain in the neck of the bottle. The time at which a sample is drawn, as well as the time at which its analysis is begun, should be noted. An effluent should be drawn to correspond as nearly as possible with the original sewage, and both it and the sewage should be taken in quantities proportional to the rate of flow when that varies (*e.g.* in the emptying of a filter bed).

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* *British Association Report, 1889.*

In order to avoid the multiplication of analyses the attendant at a sewage works (or any other person who draws the samples) might be provided with sets of twelve or twenty-four stoppered ¼ Winchester bottles, one of which should be filled every hour or every two hours, and on the label of each bottle the rate of flow at the time should be written. When the bottles reach the laboratory, quantities would be taken from each proportional to these rates of flow and mixed together, by which means a fair average sample for the twenty-four hours would be obtained.

The Committee at present are unable to suggest a method of reporting bacterial results, including incubator tests, which is likely to be acceptable to all workers.

PROCESSES OF ANALYSIS.

Since samples of sewages and of effluents are usually in a condition of rapid change, the chemical examination must be carried out as quickly as possible after collection, therefore such processes as admit of rapid working must be chosen in preference to those which are longer, even if the latter be slightly more accurate, more especially as a large number of specimens have often to be examined at once.

Physical characters, as smell, colour and turbidity, must first be noticed, then the reaction to test paper. Ordinarily this is more or less alkaline, the alkalinity being of two kinds—volatile, owing mainly to free ammonia ; fixed, due to washing soda and soap. If it is necessary to determine these features, it can be done by taking two measured quantities, say 10 to 50 cc., titrating one of them directly with standard acid, evaporating the other to a low bulk (not to dryness) over the water-bath to drive off ammonia, and titrating again. The first titration gives the total alkalinity, the second the fixed : the difference is the volatile alkalinity. The reason for not evaporating to dryness or using undue heat is that the fixed alkali is capable of decomposing many of the organic compounds, and of neutralizing itself. The fixed alkalinity is ordinarily calculated into soda, the volatile into ammonia.

Each cubic centimetre of centinormal standard acid solution required for neutralization corresponds to ·00031 grammes of sodium oxide, Na_2O ; ·00040 of caustic soda, $NaOH$; ·00053 of sodium carbonate, Na_2CO_3 ; and ·00017 of ammonia, NH_3. For a fairly clear liquid methyl orange may be used as an indicator of the end of the titration; for a thick or coloured one, delicate litmus paper is the best.

An alkaline condition is favourable to the action of bacteria, therefore it is rarely necessary to make the above determination in ordinary sewage, but it will be required where there is an addition of liquors from gas-works or chemical factories.

Occasionally the sewage is locally rendered acid by trade discharges: the degree of acidity must be determined by standard alkali run in from a burette in the same way as in the determination of alkalinity. An acid sewage would be unfavourable to bacterial action, but, as we shall see subsequently, the acidity is at once neutralized by admixture with the larger volume of sewage.

Solid matter.—A complete examination involves four determinations—

$$\text{Insoluble or suspended matter} \begin{cases} \text{Organic} \\ \text{Inorganic} \end{cases}$$

$$\text{Matters in solution} \begin{cases} \text{Organic} \\ \text{Inorganic} \end{cases}$$

To determine directly the insoluble matter, a Swedish filter paper of 12.5 millimetres diameter is dried for ½ hour at 100° C in a weighing bottle—a couple of test tubes sliding into one another answer very well—cooled in the desiccator and accurately weighed. A measured volume of the sample is filtered through, again dried at 100° C and weighed. The difference gives the total suspended matter.

In some cases it is necessary to use a hardened filter paper and an exhaust pump, as many sewages rapidly block up ordinary filter paper.

The paper and deposit are then ignited gently in a weighed platinum dish. The behaviour on heating will often give indications as to the character, whether heavily nitrogenous or fatty. The amount of ash gives the inorganic suspended matter.

In a similar manner the evaporation of the filtrate and weighing, with subsequent gentle ignition and weighing the ash, give an estimate of fixed and volatile matters in solution. On account of the presence of ammonium salts and for other reasons, the "loss on ignition" furnishes little indication of the amount of organic matter.

A shorter determination of the suspended and dissolved matters can be effected by evaporating and weighing 100 cc. of the sample before and after filtration; the first result gives the total solids, the second the dissolved; the difference being the suspended. A simple determination of the solids can be made by evaporating 100 cc. in a glass or porcelain dish.

Chlorine.—This is, of course, present in the form of chlorides, chiefly of sodium, with less quantities of potassium and ammonium, but is always recorded in terms of chlorine. It is estimated by the well-known volumetric method with a standard solution of nitrate of silver, adding a drop of neutral potassium chromate, when the appearance of a slight persistent red colour due to chromate of silver indicates the complete precipitation of the chloride. It is in all cases necessary to evaporate the measured volume of the sewage—10 to 25cc.—to dryness on the water bath before titration; the end reaction is then sharp.

A convenient strength of standard silver solution is that prepared for water analysis. 2·3944 grms. of pure recrystallized silver nitrate is accurately weighed out, dissolved and made up to 1 litre with pure distilled water. If 50cc. of the water be taken, each cc. of the standard solution = 1 part per 100,000. When a less quantity of the sample is taken, a simple calculation gives the amount of chlorine. Thus if 10 cc. of the sewage had been evaporated and had required 2·5 cc. of nitrate of silver, the chlorine is 2·5 × 5 or 12·5 points per 100,000.

The determination of chlorine is of special value, as it furnishes the chief and readiest clue to the strength or dilution of sewage, for the following reasons:

The most important liquid ingredient of sewage is the urine; this averages about 1½ litre per head per day, and contains about 0·45 per cent. of chlorine, or 450 pts. per 100,000.

Ordinary water supplies contain little chlorine, generally being from 1 to 2 per 100,000.

Weak domestic sewages contain 7 parts; stronger ones up to 40 or 50; an ordinary average may be taken to be 10 pts. of chlorine per 100,000.

FREE AMMONIA—DIRECT DETERMINATION.

The ordinary method of determining free ammonia is by distillation, combining it with the estimation of "albuminoid," as we shall see later. But as it has been proved that the organic matter in water is altered by distilling, it is preferable to estimate the free and saline ammonia actually present by diluting an appropriate fraction to 50 cc. with pure ammonia-free water and then Nesslerizing. The amount used for dilution should be such as to produce a measurable brown colour: in that case I have found that the estimation can be effected without any turbidity from lime salts interfering. 1 cc. of sewage, or 10 to 20 cc. of effluent, diluted to 50 cc. with ammonia-free water, usually gives a suitable tint for Nesslerizing.

FREE AND ALBUMINOID AMMONIA BY DISTILLATION.

The apparatus must first be freed from ammonia by distilling water through it till the distillate shows no reaction with Nessler test. Then 500 cc. of pure water, or of good tap water in which the free and albuminoid ammonia are known, are placed in the retort, and 100 cc. of the sewage added. The distillation is then carried on till 200 cc. has been collected. 50 cc. of alkaline permanganate solution are then added, and 3 pieces of ignited pumice, and the distillation is continued till another 200 cc. have been collected. Suitable fractions of the two distillates are then diluted with ammonia-free water to 50 cc., and then Nesslerized, the first result being put down as free ammonia, the latter as albuminoid. The ammonia is preferably calculated to nitrogen, as mentioned in the British Association report. In the case of acid trade effluents, ignited carbonate of soda, in slight excess, must be added before the first distillation.

In distilling sewage there is no exact point when the "free ammonia" ceases to come over, on account of the gradual decomposition of various nitrogenous matters by heat. The action of the alkaline permanganate is also not definite, therefore it is necessary to proceed in a defined manner to obtain comparative results. For some time I determined the "total ammonia" by adding to the dilute sewage alkaline permanganate at once, distilling, and Nesslerizing, then deducting the free and saline ammonia obtained by direct titration, recording the difference as "albuminoid NH_3." In this way more ammonia is obtained, but the results are not comparable with published analyses, and in effluents are more unfavourable when referred to the limits laid down by various Boards, therefore it seems best to keep to the older conventional method as originally laid down by Wanklyn. We shall have to refer again to the standards officially prescribed. To show the great variation, I have found the free ammonia in raw sewage to range from 35 to less than one part per 100,000, and the albuminoid from 6 to 0·1 pts. per 100,000, the latter, of course, being mainly rain water.

Oxygen Consumed.—This test has been variously called the "oxygen absorbed figure," the "oxygen test," or simply the "permanganate test." While in the ordinary "albuminoid" method permanganate is used in a strongly alkaline solution, and only the ammonia evolved is measured, in this process the permanganate solution is acidified with sulphuric acid, digested with the water or sewage, and after a certain time the amount of permanganate remaining is determined volumetrically. The original quantity of permanganate added being known, the loss indicates the oxygen which has been absorbed by the organic matter present.

This process, originally devised by Forschammer about 1865, was subsequently improved by Letheby and Tidy, and has attained importance as a standard comparative method on account of the ease and rapidity of its performance.

Opinions have in many cases been founded almost solely on the permanganate process of oxidation, but such a proceeding is by no means safe, as, although decidedly valuable, the test is open to the following objections :—

(1). So many modifications have been introduced in procedure that the figures obtained by various observers are seldom comparable, as instanced in the discussion at the Manchester enquiry.

(2). It mainly measures the carbonaceous matters, which are not the most dangerous.

(3). It is incomplete even in measuring these, since it has been found on trials with various definite organic matters that they varied very much in their reducing power, and some of them were very resistant to permanganate when used, according to the ordinary prescription, at low temperatures. For this reason it was customary on the Continent to boil the water with permanganate, but this was very objectionable, as it caused a spontaneous and irregular evolution of oxygen from the reagent, which gave much too high a loss.

Many years ago I found it safe to work at a temperature of 80° Centigrade, on an ordinary water bath, instead of the customary heat of 80° Fahrenheit, thereby shortening the time to 2½ hours, in place of the usual 4 hours in the cold.

(4). The greatest disturbing influence is the interference of nitrites, which are abundant in certain stages of purification, of high chlorides, and of iron and occasionally manganous salts derived from a chemical treatment. This objection has not been satisfactorily eliminated, even by the adoption of the various proposed time limits, such as 3 minutes, 15 minutes, 2½ or 4 hours.

The process, as common to all modifications, is as follows:—A measured volume of the water or sewage is placed in a carefully-cleaned stoppered bottle, and acidified strongly with a uniform amount of pure sulphuric acid. Then an excess of a standard solution of potassium permanganate is measured in, and the whole mixed by rotation. At the same time a blank is mounted with equal volumes of pure water and the reagents. Both are exposed to the same temperature for the same time. The effect on the permanganate must be watched; should it happen that the red colour pales rapidly, a further measured quantity of permanganate and of acid must be at once added, as it is necessary that the oxidizing agent should be present in excess up to the end of the time. At the end, both bottles are cooled, and a few drops of freshly-prepared potassium iodide solution is added to each, or a small crystal of the pure solid. Iodine is immediately liberated in proportion to the amount of permanganate that has remained unreduced by the organic matter. A centinormal solution of sodium thiosulphate (2.4827 grm. $Na_2S_2O_3, 8H_2O$ per litre) is then run in from a burette till the brown colour of the iodine has nearly disappeared. A few drops of fresh thin starch solution are then added, and the addition of thiosulphate continued till the blue colour has just disappeared. This titration must be accomplished rapidly, as it will be noticed that the blue colour will reappear, especially if nitrites are present.

Subtracting the amount of thiosulphate required by the sample from that used by the blank, and multiplying this number of cubic centimetres by ·00008, will give the weight of oxygen consumed in the time by the volume of sample used—and this is calculated to parts per 100,000. The standard strength of permanganate solution is 0.395 grm. of the pure crystallized salt per litre: 1cc. = ·0001 grm. of available oxygen.

The acid used is 1 part by volume of pure H_2SO_4 to 3 parts of pure distilled water. Permanganate solution is added till a faint red tint remains for some hours.

Example.—100cc of a sample, made up to 250cc with tap water + 25cc of permanganate + 25cc of acid required 18·5 cc of thiosulphate, the blank requiring 30·6cc. $(30·6 - 18·5) \times ·00008 \times 1000 = 0.968$ pts. per 100,000 of oxygen consumed.

As the oxidation is never quite final, it is important that standard conditions of time and temperature should be observed. Unfortunately a uniform method of working has not yet been agreed on between all observers, therefore the exact method used should be stated. The chief modifications are :—

(1). *Society of Public Analysts*' standard, originally proposed for waters. Two equal samples maintained at 80° Fahrenheit, one titrated after 15 minutes, the other after 4 hours : 250 cc. liquid, 10 cc. acid, 10 cc. permanganate.

(2). *Mersey and Irwell Joint Committee*, specially for sewages and effluents. Temperature 60° Fahrenheit. Two portions of 70 cc. of the sample with 10 cc. of acid and 50 cc. permanganate are titrated, the one after 3 minutes, the other after 4 hours.

At the Manchester meetings of the Society of Chemical Industry in January and April, 1898, the oxygen test was elaborately discussed. It was stated that :—

(1). "The three minutes test showed (nitrites, ferrous salts, sulphuretted hydrogen and) putrefying matter decomposing permanganate at once with acid."

(2). "The difference between 3 and 15 minutes showed matter readily putrefying and rapidly decomposing acid permanganate."

(3). "The difference between 15 minutes and 4 hours gives matter capable of putrefying, though slow to decompose."

Mr. Frank Scudder gave the following examples of oxygen consumed by Salford sewage effluents :—

Samples.	3 minutes	+ 12 minutes.	+ 225 minutes.	= 4 hours.
No. 1	0·87	+ 1·07	+ 1·31	= 3·25
2	1·13	1·07	1·52	3·72
3	0·64	0·81	1·42	2·87
4	0·66	0·96	1·50	3·12
5	0·43	0·52	1·17	2·12
6	0·56	0·65	1.24	2·45

(*J. Soc. Chem. Ind.*, Jan. and May, 1898.)

Inasmuch as the important point is to discover how far the sewage or effluent is deficient of complete oxidation, I have preferred to obtain as quickly as possible a final figure by taking 50 or 100 cc. of the sample, making up to 250 cc. with pure water (a good tap water answers in most cases), adding 25 cc. acid and 25 cc. permanganate, heating on a water bath (along with a blank) to 80° centigrade for 2½ hours, and titrating as described in the above example.

Mineral Constituents.—When there is time, much further information can be gathered from an examination of the inorganic ingredients of sewage. Where trade effluents are concerned this often constitutes a principal part of the enquiry. The processes are the same as those of ordinary analysis, but on account of the changes that occur on incineration, many of the estimations must be made on the original, and not on the ash.

Based on an average water supply of 33 gallons, Wanklyn gives the following amounts per head per day in grammes :—

Total Sewage.	Total excretal products dry.	Urinary Solids.	Fæcal Solids.
150,000	90	60	30

Sulphates are often of great importance : they are naturally derived, with sulphides, from the breaking down of albuminous matters, and also are artificially added in various forms of chemical treatment. Here is an instance from my own experience, the river being a small one :—

SULPHATES AS SO_3 IN PARTS PER 100,000.

Sewage Farm Effluents.			Water of the River.	
I.	II.	III.	Above the discharge.	Below ditto.
25·8	27·6	32·8	4·62	8·64

It can be calculated from these figures that the effluents contaminated the river to the extent of one-eighth of its volume. Allowance must always be made for the natural sulphate in the river, as many are very selenitic, especially in magnesian limestone and oolite districts. On an average, as pointed out by Wanklyn, the larger quantity of diluent water contributes at least as much sulphuric acid as the smaller volume of urine, therefore in domestic sewages the measurement of sulphates is of less value than the measurement of chlorine. Wanklyn also gives the following averages for sulphates as SO_3 in various waters and in what he names "typical sewage," *i.e.*, urine diluted with pure water to 100 times its volume. This phrase is based on the estimate of the average urine per person per day being 1·5 litres, and the average water supply 150 litres, or 33 gallons per head per day, which is a ratio of 1 to 100.

Sulphates as SO_3 in parts per 100,000.

Urine	160
"Typical Sewage"	1 6
London waters:—	
West Middlesex	2.46
Kent	5.4
New River	1.33
Loch Katrine (Glasgow) water	0.47

Phosphates.—Both urine and fæces contain in proportion to the solid matter a large quantity of phosphates both of the alkalies and of lime and magnesia, hence in testing drinking waters for sewage contamination the phosphate test is of great value. But in examining sewage effluents both from coke filters and from chemical treatment I have found that the phosphates have almost entirely disappeared, owing to the fact that they are precipitated by iron present in the materials or by lime in the water or precipitants. Therefore this determination is of less value.

Potassium.—

In urine	Na	0·4 per cent.
	K	0·08 ,,
In fæces	more K than Na.	

Porter found in the *ash* of human excrement 6·1 per cent. of K_2O and 5·07 per cent. of Na_2O (Ann. Ch. Pharm., lxxxi., 109).

Therefore, the ratio of the alkalies sometimes furnishes information as to the character, whether fæcal or urinous. It must be remembered, however, that the urine of horses and cattle contains a considerable amount of potassium.

CHAPTER III.

Chemical Analysis (*continued*)—Standards of Purification—Determination of Nitrates—Nitrites—Organic Nitrogen—Dissolved Oxygen—Carbonic Acid—Incubator Tests—Weights discharged per day—Proposed Standards for Effluents—Ratio of Chlorine to total Nitrogen and of oxidized to unoxidized Nitrogen.

Nitrates.—This determination is of very great importance. Sewages, as a rule, contain no nitrate and only traces of nitrite, while effluents may contain large amounts of both.

I have adopted a slightly modified indigo process, which determines nitrates only, the *m*-phenylene-diamine method being used for nitrites. Duplicates with the Crum method and with the copper-zinc couple, giving the total oxidized nitrogen, have agreed closely with some of the above.

For the indigo titration, a standard indigo is made by dissolving 0·5 grms. of crystallized indigotine in 20 cc. Nordhausen sulphuric acid, allowing to stand 24 hours, diluting very cautiously, filtering if necessary, and making up to 1 litre. This solution keeps well in the dark; its strength is determined, and controlled at intervals, by means of KNO_3 solutions of different strengths, and a curve is constructed giving directly the relation between the number of cc.'s used and the grms. of nitric nitrogen present in the quantity taken; for, the ratio between the cc.'s of indigo and the nitric nitrogen diminishes gradually in a curve as the solutions become stronger. The quantity of water or effluent used should not require more than 10 cc. of indigo, and is better kept at about 5 to 6 cc., or even less. In titration the strength is uniformly maintained at 25 cc. liquid to 50 cc. H_2SO_4 free from nitrate; and it is important to make blank estimations, as several samples of acid have been found to be faulty. The quantity of liquid found suitable, made up to the 25 cc. with distilled water, is mixed rapidly in a thin flask with the acid (over a sink or dish, in case of fracture), and is immediately titrated, while still hot, with the indigo. The rapidity with which this can be done has enabled me to determine nitrates *in situ*, at intervals of a few minutes on river banks or in runnings from filters, so as to ascertain the fluctuations. If samples were simply collected, transferred to the laboratory and determined by a longer process, they would have undergone such changes as to make the results quite valueless.

The amounts usually found to be suitable for a determination are :—For ordinary drinking waters, 25 cc. ; for highly nitrated waters or effluents, 10 or 5 cc. made up to 25 cc. : for sewages or low nitrated effluents, 50 or even 100 cc., with 100 or 200 cc. of H_2SO_4 may be used. With practice the slight tint of blue produced by 0·1 cc. excess of indigo is distinctly perceptible, even when the liquid acquires a brown tint after the acid is added. Occasionally the flask cracks when the mixture is made—as it should be—suddenly, so this contingency must be provided for. The titration should be done as quickly as possible, but a blue that is permanent for two minutes remains as a rule for half-an-hour.

Nitrites.—The solutions required are :—

(1). A half per cent. solution of metaphenylene-diamine in dilute sulphuric acid : if much coloured it can be bleached by filtration through purified animal charcoal.

(2). Diluted sulphuric acid ; one part to two of water.

(3). Standard Na NO_2 solution. 50 cc. of the sample are placed in a Nessler glass, 1 cc. of the metaphenylene-diamine and 1 cc. of acid added : on standing a yellow brown colour slowly develops with even traces of nitrite. The colour is imitated with standard nitrite solution in the same way as Nesslerizing*, taking care that the original and the imitation are started at the same time.

Organic Nitrogen.—As it has been proved that the organic matter in water is altered by distillation, and also changes rapidly on standing, I sought to devise a process which should, without distilling, obtain the results of a number of sewages quickly and comparatively, and yet with sufficient accuracy. I adopted the following modification of the well-known Kjeldahl process to ascertain the unoxidized nitrogen, to which I attach great importance in its relation to the oxidized nitrogen represented by the nitrates and nitrites. The quantities used for analysis are regulated by the strength of the liquid, and are, of course, larger for an average effluent than for a raw sewage. The amount aimed at in the final Nessler titration is such as will correspond to 1 cc. of the original sewage or 5 cc. effluent, as that quantity, made up to 50 cc. with ammonia-free water, generally gives a suitable colour.

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* See *Sutton's Volumetric Analysis*, 1896, pp. 404, 435.

Free Ammonia.—1 cc. is diluted to 50 cc. and Nesslerized. In this dilution the lime and other salts do not interfere, and the figure obtained is the actual saline ammonia present.

Kjeldahl.—10 cc. of a sewage or, say, 100 cc. of an effluent + 4 cc. of pure sulphuric acid are heated in a pear-shaped hard glass flask in a slanting position until the liquid becomes colourless. When about 2 to 3 cc. remain, the flask is cooled and is washed out with small quantities of ammonia-free water into a 100 cc. measure, until the volume of the liquid reaches about 40 cc. An excess *i.e.*, about 25 cc. of soda solution (25%) free from ammonia is now added, when a flocculent precipitate is thrown down. After cooling, the liquid is made up to 100 cc., transferred to a clean and dry stoppered bottle, and shaken at intervals until the flocculi—which at first float entangled with air-bubbles—subside. A suitable fraction of the clear liquid is then pipetted into a Nessler glass, diluted to 50 c.c. and Nesslerized. *This gives the total unoxidized Nitrogen as Ammonia.* The free NH_3, as found above, is subtracted, and the remainder calculated into "Organic Nitrogen (Kjeldahl)."

In order to see whether the presence of nitrite and nitrate interfered with this estimation—*i.e.*, to see whether the nitrogen of these was wholly or partly included in the result, or whether it was left out altogether, some experiments were made with an effluent from a works which was strongly urinous in character, containing in one case 31·75, and in another 23·5 parts per 100,000 of chlorine, together with 32·5 and 35 parts of free ammonia, but with no nitric nitrogen. Nitric nitrogen in the form of potassic nitrate was added to these in proportion of (*a*) 6·8, and (*b*) 13·6 parts per 100,000, and the liquids were then immediately *Kjeldahled* as above. The Kjeldahl nitrogen found per 100,000 parts was :—

First Series.—10 cc. liquid + 2 cc. H_2SO_4.

Added :—	No nitrate	6·8 parts nitric nitrogen	13·6 parts nitric nitrogen.
Found :—	42·5 nitrogen	35·0 nitrogen	37·5 nitrogen.

Second Series.—10 cc. liquid + 4 cc. H_2SO_4.

Added :—	No nitrate	6·8 nitric nitrogen ...	13·6 nitric nitrogen.
Found :—	41·0 nitrogen	37·5 nitrogen	39·0 nitrogen.

The actual amounts of standard ammonium chloride solution (1 cc. = ·00005 grm. NH_3) required to imitate a dilution corresponding to 0·1 cc. of the original, which was found to give a measurable colour, were :—

(1.) 0·85.	(2.) 0·70.	(3.) 0·75.
(4.) 0·82.	(5.) 0·75.	(6.) 0·78.

The weak point of the above process is the multiplication, but this obtains in all Nesslerizing processes where the amount of nitrogen is large. Effluents or sewages containing such a large quantity of ammonia together with nitrate are not found naturally, but these experiments show that a large excess of sulphuric acid prevents loss of nitrogen by secondary action.

The sulphuric acid must be tested for N by a blank experiment.

The organic N found as above is always higher than the N as albuminoid ammonia. Dr. McGowan proposes to call the difference the "X" nitrogen. This quantity is considerably lower in a good effluent than in a raw sewage, showing that the organic matter in the effluent is more easily broken up by the permanganate.

Dissolved Oxygen.—As it is very important to ascertain the absorption or disappearance of free oxygen in a sewage or effluent, I have adopted the simple process introduced by Winkler, which gives sufficiently near results. An accurately stoppered bottle, of which the contents are known when full, is completely filled with the sample. A convenient volume is about 300 cc. One cc. of a nearly saturated solution of manganous chloride is passed to the bottom by a long pipette, then 3 cc. of 33% caustic soda containing 10% of KI are similarly added. The stopper is inserted, and the bottle moved round so as to mix the whole. The MnO absorbs the free O and becomes brown. The whole is allowed to settle, then 3 cc. of concent. HCl are passed to the bottom without any bubbling of air, when iodine is liberated in proportion to the free O. The contents, after mixing, are poured into a porcelain dish and rapidly titrated with centinormal thiosulphate and starch, as already described under oxygen consumed.

The calculation is as follows. For this purpose a correction for temperature and pressure is not necessary.

$$1 \text{ cc. of O} = 001434 \text{ grm.}$$
$$1 \text{ cc. centinormal thio.} = \cdot 00008 \text{ grm. O}$$
$$\therefore \quad 1 \text{ cc. centinormal thio.} = \frac{\cdot 00008}{\cdot 001434} = \cdot 0558 \text{ cc. O}$$

The volume of liquid taken being known, the result is calculated to cubic centimetres of dissolved oxygen per litre of the sample. To simplify the calculation, a coefficient should be obtained, converting the cc. of the thio. required by the volume in the bottle used, directly into cc. of O per litre.

Example.—The bottle held 342 cc. when full (this volume is etched on the bottle):—

cc.		cc.		O		O
342	:	1000	: :	·0558	:	·163

Therefore, for this bottle, 1 cc. thio. = ·163 cc. O per litre.

A table can then be constructed giving the direct reading. The value of this determination can be gathered from the fact that in all the later purifying changes of sewage, oxygen is absorbed. It has been too much neglected, owing to the difficulty of the methods usually proposed, and the complication of the apparatus. To be of practical value it must be done on the spot, within a few minutes of collection, and without change of temperature, agitation, or exposure to air, so that of course accuracy must be to a certain extent subordinate to rapidity.

To begin with, a trial should always be made with the ordinary tap water, which may be assumed to be fully aerated. It will be found to contain about 7 cc. of O per litre. According to the laws of solution of gases, at higher temperatures in summer rather less, in winter more, will be dissolved. Roscoe and Lunt in their table give at 5° C, 8·68 ; at 10° C, 7·77 ; at 15° C, 6·96 ; at 20° C, 6·28 cc. of O per litre in saturated water*. It is rarely that the temperature of good effluents falls below 10° C, owing to the heat produced by the oxidation of the organic matter. I have found in trials of the tap water in different parts of England 7·2, 7·33, 7·24, and similar numbers of cc. of dissolved oxygen per litre.

This process is interfered with by the presence of large quantities of organic substances which absorb the liberated iodine, and by the nitrites which occur in many effluents themselves setting free iodine when acidified. Such interference can be to a great extent prevented by working very rapidly, running in the thiosulphate till the brown colour of iodine has just disappeared—not using starch.

Useful data to record are :—

7 cc. of oxygen per litre = 1 part by weight in 100,000.

1 cub. ft. of O = 40·6 grms., or 1 gallon of O = 5·52 grms.

Carbonic Acid in Sewage and Effluents.—The importance of this determination was recognised by the late Professor W. A. Miller, who in 1859 determined the amount of carbonic acid in the "sewage-laden" water of the Thames at Woolwich, and in the clearer upper reaches at Kingston. His results show the following number of cc. of dissolved gases per litre :

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*J. Chem. Soc., 1889, p. 552.

	Kingston.		Woolwich.
CO_2 … … … …	30·3	…	48·3
N … … … …	15·0	…	14·5
O … … … …	7·4	…	0·25
	52·7	…	63·05

The organic matter of the sewage entering the lower reaches of the river is thus oxidized at the expense of the dissolved oxygen, and carbonic acid is produced, while the nitrogen being near the saturation point in each case, as it must be in a liquid freely exposed to air, we cannot gather from its figure how much nitrogen has been evolved as gas. But the amount of dissolved CO_2 in a sewage or effluent will be always much lower than the organic matter which has produced it, on account of the loss by diffusion. Useful information, however, may be sometimes obtained in the following way.

Equal volumes (about 100cc.) of the sewage and of the corresponding effluent are precipitated in closed vessels with excess of clear lime water, and, after settling, filtered; the precipitated carbonate of lime is washed with boiled distilled water, transferred to a dish and titrated with decinormal HCl, using methyl orange as indicator. The increase in the amount of carbonic acid found in the effluent will indicate the *minimum* amount of carbon that has been oxidized in the purification process. 1cc. of decinormal acid = ·0022 grms. of CO_2, or ·0006 grms. of carbon.

I will give some examples from my own experiments.

Sample	Cc. Acid per Litre.			Grms. CO_2 produced per 100,000	Equal to grms. carbon oxidized per 100,000	Equal to lbs. of carbon oxidized per million gals. sewage
	Sewage	Effluent	Gain			
1	25·2	82·0	56·8	12·5	3·41	341
2	38·0	94·4	56·4	12·41	3·38	338
3	60·0	105·6	45·6	10·03	2·74	274

The last column illustrates one advantage of stating the results in parts per 100,000. As a gallon of water is 10lbs., they are translated at once into lbs. per million gallons by multiplying by 100.

Incubator Tests.—From the very beginning it has been known that a water which was good and sweet would "keep," and that another which was bad in origin would "foul." This elementary fact seems to have been first utilized as a scientific test by Dr. Dupré in 1884. He stated in reports to the Local Government Board that if a pure thoroughly-aerated water be kept out of contact with air for say 10 days, it will be found to have remained fully aerated. Sewage-polluted water also, when sterilized by heating, remains fully aerated. But if the water contained any impurity capable of combining with oxygen, and also contained living organisms, the amount of aeration would diminish. It was hoped that the degree of diminution would give some measure of the number of organisms present—this was at a time when the *number* of organisms was more considered than their species, functions or activity. The process involved determinations of free dissolved oxygen similar to those we have described, and is still of considerable value.

The late Charles Heisch in 1870 mixed the sample with pure cane sugar and exposed it to sunlight, noticing the effect as to fouling and growths.

The incubator test made prominent at the Manchester enquiry of 1899 is similar in principle but differently carried out. The official description is :—

"A determination is first made of the O absorbed from permanganate by the original sample in three minutes. A bottle is then completely filled with the sample, and closed and placed in the incubator at 80° F. for five days. The three minutes absorption of O is then again determined. If any putrefaction has taken place the oxygen absorbed in three minutes will increase in amount owing to the more ready oxidizability of the products of putrefaction. On the other hand, if the sample keeps sweet, there will be a slight decrease in the three minutes absorption after incubation, owing to slight oxidation of the impurities which has taken place during the five days by means of air dissolved in the sample."

Any change of odour or appearance of putridity is also carefully noticed.

In the Manchester reports a great number of examples of the results of this incubator test are given.

This test, although extremely useful, is arbitrary in character, as an effluent is not intended to be stored by itself but when finished, to be discharged at once into water which is moving and aerated. If an effluent passes the incubator test it can be discharged into a dry ditch without fear of subsequent putrefaction. At Manchester they have determined the behaviour of mixtures of equal volumes of filtrate and ship canal water and have found that almost invariably such mixtures remain sweet. The ship canal water alone, when tested in this way, frequently gives an unsatisfactory result, so that the effluent actually improves the waters of the ship canal.

The Mersey and Irwell Joint Board incubate at 65° F. for seven days, but by working at the higher temperature of 80° F. as above, results are obtained in a shorter time.

The *weights discharged per day* per average person have been given as follows* :—

	Grammes per day.	Corresponding to parts per 100,000 in the sewage :—	
		With a water supply of 100 litres (22 gallons) per head.	With a ditto of 150 litres (33 gallons) per head.
Wet fæces :—	90·7	90·7	60·4
Organic N	1·34	1·34	0·92
P_2O_5	1·88	1·88	1·26
Urine :—	1174	1174	783
Organic N	10·52	10·52	7·0
P_2O_5	2·11	2·11	1·41
In both together :—			
SO_3	1·88	1·88	1·26
Cl	5·04	5·04	3·36

The amount of fæces given in the above figures includes the water associated with them: the fæcal solids insoluble in water and dried free from associated water amount to from one-half to one-third the above, and therefore the quantity of matter required to be brought into solution by a liquefying or hydrolytic process is approximately 20 to 45 parts per 100,000. In chemical processes where sludge is formed, this being still wet and associated with water will amount to 60 to 90 parts per 100,000. These are minimum figures and, of course, in precipitation processes, the weight of sludge is increased by the weight of lime or other precipitant mixed with the fæcal solids. Road detritus, in the absence of settling tanks, and solids of non-excrementitious origin also frequently cause the above amounts to be exceeded.

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* Frankland, Rivers Pollution Commission, 1870.

Proposed Standards.—Sewage does not properly include manufacturing waste liquids. Many authorities prohibit the admission of such refuse into the sewers without preliminary treatment. For example, the West Riding of Yorkshire Act for 1894 includes as sewage to be treated by the local authority "unpurified urine, excrementitious matter and liquid refuse of any house or premises, blood and the washings of the slaughter-house containing urinary or fæcal matter," but excludes any liquid rendered poisonous, noxious, or polluted in the course of some manufacturing process.

Amongst the standards which have been proposed in the past, or have been adopted by local bodies, are the following, some of which have been repeatedly quoted in papers on the subject, while others are gathered tentatively from published documents, or from a consideration of decisions in disputed cases. None of them, however, have strictly the force of law; in fact, some have actually been disclaimed by the bodies to which they were attributed. The proportions are parts per 100,000:—Rivers Pollution Commissioners—Organic carbon, 2·0; organic nitrogen, 0·3. Thames Conservancy—Organic carbon, 3·0; organic nitrogen, 1·1. The Thames Conservancy state that they require a higher standard for effluents just above the intakes of the water companies than for those below. Derbyshire County Council—Albuminoid ammonia, 0·1; oxygen absorbed, 1·0. Ribble Board—Albuminoid, 0·1; oxygen absorbed, 2·0. Mersey and Irwell—Albuminoid, 0·14; oxygen absorbed 1·40. Provisos as to amount of suspended solids, acidity, alkalinity, metals, etc., are inserted in some, and have special reference to manufacturing effluents. But in all these arbitrary limits, no account is taken of the volume of the river into which the effluents are discharged, although attention was long ago drawn to the purifying action of river water. The London County Council have recognised the fact that an oxidizing agent added to the effluent at the time of contact with the river prevents any foulness. Provided, therefore, a river is well aerated, or an effluent is well nitrated, or an oxidizing agent is supplied in sufficient quantity at the time of contact, an effluent may contain a larger quantity of organic matter than has been sanctioned in the past, and variations in such quantities are permissible under conditions varied in the above way. I have already mentioned in Chapter I. the limits that Rudolph Hering has officially fixed in the United States for the amount of free ammonia that may be allowed to arise from discharges into a stream, and the conclusions of the

Engineer to the Massachusetts Board. I pointed out that their limits corresponded to about 50 volumes of river water to average sewage in this country, and that such conditions are only possible under very special circumstances, while the limit is much greater than we have found necessary in England. In other words I agree with this author that the quality of the stream and not of the effluent should be taken as a basis, and that some fixed distance below the outfall in midstream should be specified as the locality at which samples should be taken.

Mr. Dibdin's Fish Test.—Mr. Dibdin has recently put forward this test, which he describes as follows:—"He had long since adopted in his own mind a physiological standard, viz., that the quality of an effluent should be such that fish could live healthily in it, ... such a definition involves necessarily the absence of poisons and the presence of oxygen." But while an effluent which kills fish is obviously unhealthy, it does not follow that one where fish will live is therefore a good one. It is well known that fresh-water fish are gross feeders, and fish in large numbers are often seen to congregate at the mouths of sewers where fæcal matter is visibly floating, being attracted by the fragments of food and insects carried down by the sewage. Fish, in fact, are more affected by muddy water and by chemicals from factories than by excreta.

To show how far rigid conclusions may be carried, Mr. Naylor, of the Ribble Joint Board, sent me copies of his official reports to that authority, in which I noticed for example that on January 7th, 1897, an effluent of 150,000 gals. with ·101 albuminoid ammonia and 1·95 oxygen consumed was passed as good, but one of 123,000 gals. only, and 1·6 oxygen consumed with an albuminoid ammonia of ·108 is only considered fair.

Many waters are inoffensive which contain a comparatively high amount of albuminoid ammonia. The following, on the other hand, is an example of a putrescent and otherwise objectionable liquid which did not show a corresponding excess of albuminoid. A putrid meat solution was diluted with water in the proportion of 1 to 6,000, and the fluid, which smelt strongly like sewage, was analysed like an ordinary sewage effluent. It gave in parts per 100,000, free NH_3 ·025, albuminoid NH_3 ·083; oxygen consumed, ·044; no nitrite or nitrate. This liquid remained putrid and foul-smelling for more than a week.

It is obvious, therefore, that an arbitrary standard based upon an albuminoid figure is valueless.

The processes at work in destroying the putrescible matter in sewage involve its transition into products yielding albuminoid and free ammonia ; an increase in the free ammonia, therefore, is actually a proof that so much destruction of nitrogenous organic matter has occurred. Albuminoid ammonia in an effluent may also be a good sign, indicating either that organic matter as sediment has gone into solution, or that stable soluble matter has been partially broken up. In a research on the different actions of sodium peroxide and of permanganate on the organic matter in water,* I have shown that different kinds of "albuminoid ammonia" are possible, remarking that waters containing fresh sewage which has been partially oxidized by the peroxide yield the remainder of their ammonia to the alkaline permanganate much more rapidly than when the water had not been so treated, and suggesting the presence in waters of organic nitrogenous matters which, when partially oxidized, are then in a condition to be completely broken up by the stronger reagent. When the albuminoid ammonia process was introduced it was well known that there was a varying relation between the quantities of albuminoid ammonia and the amounts of different kinds of organic nitrogenous matter. The works of Preusse and Tiemann, Mallet, Leffmann and Bean, P. Frankland and others have confirmed the inference that, although a useful indication, too much importance must not be placed on this item of the analysis.

An effluent that is in an active state of wholesome bacterial change, in presence of free and potential oxygen, will conform to Adeney's proposed test :—"The limit of impurity to be allowed in a water should be such that when a given volume of it is mixed with a given volume of fully aerated river water, and the mixture kept out of contact with air, a decided oxidation of the ammonia originally present into nitrous or nitric acid shall be indicated." It will be seen that this proposal of Mr. Adeney's is practically an incubation test, and the result obtained by it should be similar to those given by the incubator test already described as adopted in the Manchester experiments.

RATIO OF THE CHLORINE TO THE TOTAL NITROGEN.

In perfectly fresh excreta, taking the solids and liquids together, the total nitrogen somewhat exceeds the chlorine. This proportion will remain unchanged when diluted with water containing only the ordinary small amount of chlorine, as long as the nitrogen remains in fixed forms. Therefore the ratio is applicable to fresh sewages generally, independent of dilution, but will be immediately altered by the production of gas. Let Cl and N be the parts of chlorine and nitrogen respectively, the "residual ratio" will be :—

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* *British Association Reports*, 1893

$$R = \frac{N \times 100}{Cl}$$

or, in cases of great dilution, with a high chlorine W in the water supply :—

$$R = \frac{N \times 100}{Cl - W}$$

The simpler formula is usually sufficient. In the original excreta the number R will be somewhat over 100, in fairly fresh sewage it will be about 100 ; in bacterial effluents, on the other hand, the fall of R will indicate the gaseous dispersal of nitrogen. With chemical or mechanical treatment R will fall, owing to the abstraction of matter as sludge. Where heavy nitrification has been the main feature, there may be little or no fall, this afterwards occurring rapidly in the process of denitrification, when the effluent is admixed with other water.

The following table bears on this point :—

TABLE OF THE RELATION OF NITROGEN TO CHLORINE, AND OF OXIDATION.

	Chlorine	Total Nitrogen	R. $\left(\frac{N \times 100}{Cl}\right)$	Percentage of Oxidation
Raw Sewages :—				
Exeter	7·5	6·37	86	Trace
Sutton	8·99	8·81	98	0·2
London	10·4	7·06	68	Trace
Effluents and Filtrates :—				
London Outfall (removal of the N by precipitation)	10·5	4·26	41	Trace
Exeter Septic Tank	7·5	5·96	80	·3
Exeter Coke Breeze Filtrate	7·5	3·42	46	32
Sutton Bacterial Tank	6·94	2 97	43	19
Sutton Coke Breeze Filtrate	6·84	2·00	30	56
Ashtead Tank Effluent 1	6·3	6 60	105	0
Ashtead Filtrate	6·4	7·16	112	84·3
Ashtead Tank Effluent 2	5·5	5·35	97	0
Ashtead Filtrate	5·5	4·52	82	96·7

As nitrogen is significant of the more dangerous forms of pollution, a calculation of the ratio between the different forms of nitrogen furnishes more useful information than a mere consideration of its amount, inasmuch as nitrogen compounds when oxidized are harmless, but when unoxidized are liable to occasion smells, and to be in other respects deleterious. A certain quantity of nitrogen is lost as gas during the changes, but the residue will give a minimum measurement of the original sewage strength. The proportion between the oxidized and unoxidized nitrogen will then denote the extent to which the sample has been purified. A judgment can therefore be formed from the sample without an analysis of the original sewage, as the chlorine contents also give a clue to the strength, and thus such a method would have an advantage over the ordinary system of calculating sewage purification, as it obviates the difficulty of obtaining conformable samples. Even where a correction is made to a standard chlorine value in comparing the sewage entering and the effluent leaving a certain works, the system I suggest will still have great advantages. As ammonia must be recognised as a preparatory or transition, and not a finished product, it must be considered as part of the residual unoxidized sewage, and only indicates progress towards complete purification, and gives a criterion as to whether a process is working satisfactorily. A large number of the failures in sewage disposal methods have been owing to the effort to obtain by chemical treatment or filtration a liquid from sewage which should bear some resemblance to drinking water; such an end is impossible without impracticable expenditure, time, and space, attended by disastrous breakdowns at intervals. Fortunately methods have been found which by natural agencies allow us to carry the purification to a rational and harmless stage, when such factors as time, light, volume of oxygen, and various life of a river will be more than sufficient to deal with the effluent. A few examples to show how the percentage of oxidation reveals the purification effected by different agencies may be quoted here:

	Oxygen Consumed.	Parts per 100,000 of Nitrogen.				Percentage of Oxidation
		As NH_3	Organic	Total Un-oxidized	As Nitrate and Nitrite	
A Raw Sewage ...	6·66	3·0	6·12	9·12	none	none
A Filtrate Effluent ...	0·78	2·4	0·92	3·32	1·16	26·0
Another ditto... ...	0.36	0·92	0·44	1·36	1·09	44·5
London River Water	0·20	0·0016	0·049	0·051	0·305	86·0
Same Filtered ...	0·176	none	0·026	0·026	0·254	91·0
Deep Well in Chalk	0·013	none	0.008	0·011	0·450	97·6

CHAPTER IV.

BACTERIA occurring in Sewage.—Their Identification and Numbers, and Morphological Characteristics.—Bacterial Tests for the Purity of Effluents.—Possibility of the Survival of Pathogenic Organisms.

THE bacteriological examination of sewage is attended with some difficulty owing to the enormous number and variety of micro-organisms that are present. Drs. Clowes and Houston in their first report to the L.C.C. on the bacteriological examination of London sewage (June, 1898) found that the number of bacteria per cubic centimetre in the Barking crude sewage varies between 7 millions and 500,000 and in the crude sewage at the Crossness outfall between 5 and 2½ millions. It is obvious millions cannot be dealt with, and therefore a minute average fraction of the sample, bearing a definite relation to the whole, has to be examined. If we attempted to measure such small quantities directly it would neither be accurate nor representative of the whole; a systematic dilution of the sewage has, therefore, to be followed.

Collection of Samples.—Samples of sewage are collected in small glass-stoppered, or better, rubber-stoppered flasks, holding about 50 cubic centimetres which have been previously sterilized by heat. The flasks are filled so as to allow a small air space, placed in water-tight tins, and at once packed in ice and despatched to the laboratory. If possible, the culture plates for counting the number of bacteria should be started on the spot and then conveyed to the laboratory for incubation, as micro-organisms multiply exceedingly rapidly in sewage owing to the quantity of organic matter that is present, though this is to a great extent retarded by the ice.

Dilution of the Sewage.—To inoculate the different cultures for isolating and counting the various bacteria present, the sewage is diluted in the following manner:—

A number of 1 cc. pipettes and flasks holding about 150 cc. are plugged with cotton wool and sterilized. 99 cc. of sterile water are then placed in each of the flasks, and 1 cc. of the sewage is then added to No. 1 flask and well shaken, with another pipette 1 cc. of this dilution (corresponding to 0.01 cc. of the original) is transferred to No. 2 flask and so on. In this manner, minute fractions of a cubic centimetre of the original can be taken with great accuracy, provided that each dilution is well shaken so as to evenly distribute the bacteria.

Nutrient Media.—Cultivations are made with various media, such as nutrient gelatine, agar-agar, meat broth, milk, blood serum, potatoes, albumen, etc., etc. The most important of these is the nutrient gelatine which consists of meat broth containing 10 to 15 per cent. of gelatine, 1 per cent. of peptone, and 0·5 per cent. of common salt; it is rendered neutral or very faintly alkaline and clarified with egg albumen. While hot, quantities of about 10 cc. are run into test tubes fitted with cotton wool plugs, the cotton wool and tubes having been previously sterilized by heat. These tubes are then fractionally sterilized by steaming for half-an-hour on three successive days. When properly prepared, the jelly is quite bright, should not melt at 22°C., and should undergo no alteration on keeping, as the cotton wool plugs, while admitting air, exclude the micro-organisms floating in it. The agar-agar is prepared in a similar manner, 2 per cent. of agar-agar being substituted for the gelatine—this remains solid at blood heat and is, therefore, used for cultures at the higher incubation temperatures. These tubes of gelatine and agar are always stocked and they are employed for the following cultivations.

1. Plate Cultures.—This method was originally devised by Koch, and is almost invariably resorted to for the isolation of bacteria. A gelatine tube is melted at a temperature of about 30°C., one cubic centimetre of the sufficiently diluted sewage is added with a pipette, the tube is gently shaken, and the contents poured into a shallow glass dish with a close-fitting lid—this "Petri dish" and the pipette having been previously sterilized in a hot-air sterilizer. The gelatine is now allowed to set, which can be hastened by placing the dish on a block of ice, and it is then incubated at 20°-22°C., and examined from day to day. If the sewage has been properly diluted, after about 48 hours according to the temperature a number of centres of growth become visible in the gelatine. These "colonies," which are due to proliferation of single scattered organisms, will usually consist of pure cultures of the original germ, and soon exhibit characteristic differences. Some form cup-shaped depressions of liquid: others refuse to liquefy the gelatine. The colonies may be either raised above the surface or penetrate deeply into the gelatine ; their outline may be ragged or circular, branchings from the centre or concentric circles may appear, they may remain colourless, or develop peculiar pigments.

If there is no guidance as to the strength of the sample under examination, a large number of these gelatine plates has to be prepared from varying quantities of the sewage, in order to hit off the right dilution. A great many of the bacteria present in sewage and effluents consist of putrefactive germs which are capable of liquefying the nutrient gelatine with great rapidity, and, therefore, if the plate be too crowded, containing say more than 200 colonies, the entire gelatine will become fluid owing to the junction of the liquefying areas, before many colonies which do not develop so rapidly are visible to the naked eye.

The colonies are counted with the aid of a magnifying glass, the Petri dish being placed on a glass plate ruled in centimetre squares (Wolffhügel's apparatus), and as each colony originates from one individual a factor is obtained from which the number of organisms present in the original sewage can be calculated. This is returned as "organisms per cubic centimetre"; some, however, which are incapable of growing under these conditions will be omitted in the enumeration, such as the nitrifying, thermophilic and anaerobic organisms.

In the London County Council experiments by Dr. Houston, gelatine plates were used in estimating the total number as follows :—" From 0·1 to 1.0 cc. of crude sewage or effluent diluted with 10,000 times its volume of sterile water (*i.e.*, 0·00001 to 0.0001 cc. of the original fluid) was added to 10 cc. of sterile gelatine contained in a test tube. After the gelatine had been melted, it was poured into a Petri's capsule, and after solidification had taken place the plate was inverted, incubated at 20°C., and the colonies subsequently counted at as late a date as the liquefaction of the gelatine and the crowding of the colonies allowed of."

The number of spores of bacteria was determined in the following manner :—" To 10 cc. of sterile gelatine in a test tube was added 1 cc. of diluted sewage or effluent (1:10), and the mixture heated to 80°C. for ten minutes and then poured into a Petri's capsule. After the gelatine had become quite solid the plate was inverted and incubated at 20°C."

The organisms which multiply at blood heat are examined by means of agar plate cultures prepared similarly to the gelatine plates, and incubated at 37-38°C. for one or two days.

2. *Anaerobic Cultures.*—As I have already stated there are a

number of organisms in sewage which do not thrive in the presence of oxygen, and in order to develop these anaerobes they must be incubated in an atmosphere of some indifferent gas, such as hydrogen or preferably nitrogen. The cultures may be enclosed in a jar filled with the gas or containing a solution of alkaline pyrogallate to absorb the oxygen in the air.

I find that a certain amount of confusion has arisen from the application of the words aerobic and anaerobic in two slightly different meanings—one with reference to the chemical changes that occur, the other with regard to the organisms that produce them. As the words simply mean "living with air," and "living without air," the chemist has applied the term "anaerobic" to changes occurring by life in which free oxygen takes no part; many of these are due to hydrolysis, or the addition of water, like that of urea into ammonium carbonate, or cellulose into starch, dextrin, and sugar. In this sense, the word "anaerobe" implies an organism that effects its changes in surrounding matter without oxidation. But a bacteriologist often uses the term "anaerobe" in the sense of "obligate anaerobe," *i.e.*, one that not only does not require oxygen, but is actually inhibited, or even killed by its presence. The obligate anaerobes, as is shown by our table of bacteria in sewage, are, though exceedingly active, comparatively few. The *facultative* anaerobes on the other hand, those that can live either with or without oxygen, are much more numerous, as being the ones most suited to a liquid which contains little or no oxygen, but may at any time become oxygenated. Thus yeast, which was classed by Pasteur as "both an aerobian and an anaerobian," *i.e.* as facultatively anaerobic, when in presence of excess of oxygen, multiplies vigorously, but does not act as a ferment, whereas in sugar solutions containing no oxygen it multiplies with less activity, but the fermentive character is most marked, the yeast attacking the sugar, and obtaining any oxygen it requires from it or from the water present. Boussingault found that normal fermentation could be carried on *in vacuo*, and was greatly promoted by removing the carbonic acid and alcohol as fast as they were formed, and thus preventing their retarding action. In the same way with bacteria, a better result is attained when the liquid products are continuously removed, as in the bacterial tanks of Cameron and Moncrieff, and the nitrifying trays of the latter, than where periods of stagnation occur, as in the intermittent system.

In order to preserve pure cultures and to identify growths obtained in the different plates, as soon as the colony is sufficiently developed it is carefully examined under a low power with the microscope, and minute portions transferred with a sterilized platinum needle to various culture media, and the development of these sub-cultures noted from time to time.

3. *Streak Cultures.*—A tube of melted gelatine or agar is allowed to solidify in a slanting position, so as to expose a long surface, the tube is then inverted, the cotton wool plug carefully removed and the surface of the jelly lightly scratched with the infected platinum wire, the plug is then singed and quickly replaced. Streak cultures are specially adapted for the development of pigments which generally require free access of air for their production.

4. *Stab Cultures.*—The tube is held horizontally, the inoculated wire plunged steadily nearly to the bottom, withdrawn, and the cotton wool plug replaced. Certain ramifying growths show themselves better under this method, and moreover the occurrence of a growth in the deep layers will often reveal the presence of facultative anaerobic organisms which can afterwards be dealt with.

5. *Shake Cultures.*—The fluid gelatine or agar is inoculated with the organism, gently shaken, so as not to produce air-bubbles, and then allowed to solidify. If the organism produces gas during its growth, the jelly will soon become impregnated with small bubbles of the gas, which gradually increase in size and number. B. coli communis, a non-liquefying bacterium present in large numbers in sewage, gives the shake reaction after six hours incubation at 38°C.

6. *Roll Cultures.*—This method of cultivation can be employed in the place of gelatine plates when it is required to start the cultures *in situ*, but they must be kept cool and are soon spoilt by the liquefying bacteria of sewage. Quantities of about 10 cc. of nutrient gelatine are sterilized in wide test-tubes; these are inoculated in the usual manner, and a rubber cap is drawn over the cotton-wool plug. The tube is then held horizontally in cold water and rotated with the fingers till an even layer of the gelatine has set round the walls of the tube.

7. *Surface Plate Cultures.*—A tube of gelatine is melted and poured into a Petri dish; the dish is then covered and set aside in a cool place so that the gelatine shall become quite firm. 1 cc. of the diluted sewage is then added and rapidly spread over the

surface of the gelatine with a sterile bent glass rod and the cover replaced. After a few hours the nutrient gelatine will have absorbed the water, depositing all the bacteria on its surface and thus preventing any colonies from starting in the depth of the gelatine. In this manner after some days incubation the growths are all obtained as surface colonies, and consequently are easy to examine and subculture, whereas, deep-seated colonies often remain mere dots, and in many cases do not show any differences.

In addition to the several methods of cultivation which I have described, special reagents may be incorporated with the nutrient media, such as litmus to demonstrate the production of acidity or alkalinity, an iron salt for H^2S, magenta to detect any bleaching action, sugar to aid the production of gas, hydrochloric and carbolic acids to inhibit the growth of certain bacteria. Also a number of micro-organisms, including many pathogenic forms, grow luxuriantly in a particular medium, their development in other culture materials, if any, being poor and not characteristic; indeed, all attempts to cultivate some have hitherto entirely failed, among which were the nitrifying bacteria until recently when it was found that they required food material practically free from fermentable organic matter; these organisms have, therefore, to be isolated by means of a silica-jelly plate, proceeding, according to Kühne, as follows :—

A solution of potassium silicate of about 5 per cent. strength is mixed with 10 per cent. hydrochloric acid, placed in a parchment paper dialyser, and floated for 2 or 3 days on running water, protected from dust, until, after floating the dialyser on distilled water for 30 minutes, the water is practically neutral, and gives only a faint reaction with nitrate of silver, showing that the chloride and free acid have been washed out. The solution of silicic acid should be clear and mobile; if there are a few white flocks in it they must be strained out; if many, the solution is spoilt. Two solutions are made containing the following quantities of nutritive inorganic constituents in grammes :—

(*a*). Ammonium sulphate, 0·4; magnesium sulphate, 0·05; calcium chloride, ·0005; distilled water, 50 cc.

(*b*). Potassium phosphate, 0·1; sodium carbonate, 0·075; distilled water 50 cc.

They are separately sterilized, mixed in a sterile flask and closed with a sterilized stopper. The silicic solution is boiled gently down till a sample on cooling and mixing with one-third of its volume of the above saline solution sets in about 10 minutes into a sufficiently firm jelly. The saline solution is apt to deposit slightly, but if kept sterile, is not rendered unfit for use. The liquid to be tested is mixed with the two solutions and at once poured into Petri dishes to set, provision being made for an ample supply of oxygen. Plates of magnesia-gypsum containing the above salts are now used by Omeliansky.

A convenient method of testing the bacterial efficiency of a process is to add a portion of the liquid to sterile sewage, obtained by means of a Pasteur filter, and to analyse it after a certain time. Thus, Dr. Sims Woodhead, in November, 1896, isolated at Exeter, five distinct species of bacteria from the crude sewage, and three from the tank effluent, and found that these were practically the only ones which could grow freely in the sewage. He filtered samples of the tank effluent through a Pasteur-Chamberland filter into sterile flasks and tubes, and inoculated them in duplicate with cultures of the various organisms separated by the plate culture method. After six days growth at the ordinary temperature, I determined for him the nitrate and nitrite with the following results:—

		Nitric N, parts per 100,000	Percentage increase of nitric acid.	Relative amount of Nitrous N, 10 being taken as the standard of measurement.
Sterile tank effluent		0·661	0	10
Ditto + crude sewage organism	No 1.	1·417	+ 114	6
Ditto ditto	No. 2	1·386	+ 109	10
Ditto ditto	No. 3	1·291	+ 95	4
Ditto ditto	No. 4	1·417	+ 114	6
Ditto ditto	No 5	1·638	+ 147	1
Tank effluent organism	No. 6	0·3	− 55	excessive
Ditto	No. 7	0·819	+ 24	8
Ditto	No. 8	0·567	− 15	8
Mixture of three organisms ...		1·449	+ 119	8
Mixture of all the organisms...		1·23	+ 86	10

It is evident from these experiments that the sewage contained organisms (No. 6) which reduced nitrate to nitrite, and others, (No. 5) which oxidized nitrites to nitrates, so that under practically the same conditions two different changes can take place.

Microscopical Examination and Staining.—Colonies are examined with a low power, about 1 inch, the Petri dish being inverted under the microscope, or if necessary, the cover is removed. A minute portion of the growth is then mixed with a drop of pure water on a cover-glass, dried by a very gentle heat, and it is fixed by rapidly passing twice or thrice through a flame with the residue upwards. A drop of the stain is then spread over the preparation, or it may be floated face downwards on the staining solution, which sometimes requires warming, and after a few minutes the specimen is carefully rinsed with water, dried, and examined under the microscope with a $\frac{1}{12}$th inch immersion lens. For such rapid work methyl blue is a most useful stain; fuchsine, gentian violet and other dyes are also used, sometimes with a mordant for demonstrating flagella, spores, etc. Many bacteria do not stain readily, and the manner in which an organism takes up a stain often helps in its identification. Houston points out that in London sewage and in the bacterial beds, there are some bacteria which, after being stained with hot carbol-fuchsin are "acid fast" and thus resemble the tubercle bacillus. An *impression preparation* is taken by gently pressing the cover-glass on the colony, which must be on the surface and not too advanced in growth. The cover-glass is then removed with the aid of the forceps, and after being allowed to dry, the preparation is fixed, stained and mounted. When examined in this manner, the bacteria often show their natural grouping, which is not defined in an ordinary preparation from the colony.

To study the growth of an organism, and to decide whether it is motile, a "hanging drop" examination should be made. A drop from a fluid culture is transferred by a platinum loop to the centre of a thin cover-glass held by forceps, and this is inverted over the well of a hollow-ground slide, round which a ring of vaseline has been painted so as to lute down the cover-slip. The edge of the drop is at first focussed with a low power, and then with the immersion lens.

The staining and microscopical examination of the various bacteria occurring in sewages require great care and experience, and beyond the rough outlines which I have given we cannot attempt to enter into the different processes.

The size of organisms is recorded in micro-millimetres $= \frac{1}{1000}$ of a millimetre (about $\frac{1}{25000}$ of an inch) commonly abbreviated μ. In the absence of a scale, a comparison may be made with bodies of known size, such as red blood corpuscles.

Sterile water, which is required in large quantities, can be obtained by a Pasteur-Chamberland or Berkefeld filter. Apparatus, cover glasses, etc., must be carefully freed from grease and dust, and all vessels for cultures are sterilized before use by heating for some hours above 100° C. Perishable articles, like rubber corks, are soaked in a 1 per cent. solution of formalin and then thoroughly rinsed with hot sterile water.

The enumeration of all the bacteria occurring in a sewage would of course be impossible, and a bacteriological examination is usually confined to the following items :—

1. Number of organisms per c.c. capable of growing at room temperature *(a)* aerobic, *(b)* anaerobic.
2. Number of organisms per c.c. at blood heat *(a)* and *(b)*.
3. Number of organisms per c.c. that liquefy gelatine.
4. Special tests for spores and their number per c.c.
5. Identification of important species and number per c.c.
6. Special tests for pathogenic forms.

1.—The number of organisms per c.c. is obtained from the gelatine plate cultures. As pointed out previously, this figure varies enormously, and to give some idea of what may be expected, I have tabulated a few results obtained by various observers from raw sewages and effluents.

	Organisms per cc.	*Ditto Liquefying.*	*Observers.*
LONDON.			
Barking outfall, crude sewage	5 to 7 millions	220,000 to 900,000	Clowes & Houston
Crossness outfall crude sewage (2nd report)	6 ,,	860,000	
Crossness, 4ft. coke bed effluent	4½ ,,	762,100	
EXETER.			
Crude Sewage	3 to 5 ,,	300,000 to 500,000	Sims Woodhead
Septic Tank	3 to 5 ,,	150,000 to 200,000	
Tank Effluent	1 million	300,000 to 400,000	
Filter Effluent (end of filtration)	900,000	100,000	
Filter Effluent (Well A after running off 3 minutes)	3 to 5 millions	30,000	

Experiments conducted at Chorley for the Royal Commission upon the average number of organisms present in the sewage during the successive stages of treatment, gave the following results :—

	No. of Samples.	*No. of Gelatine Plates.*	*Average No. of Bacteria per cc.*
Crude Sewage	11	124	4,084,827
Sewage and Precipitate ...	8	93	1,344,925
Tank Effluent	9	107	398,695
Filter Effluent	11	127	45,755

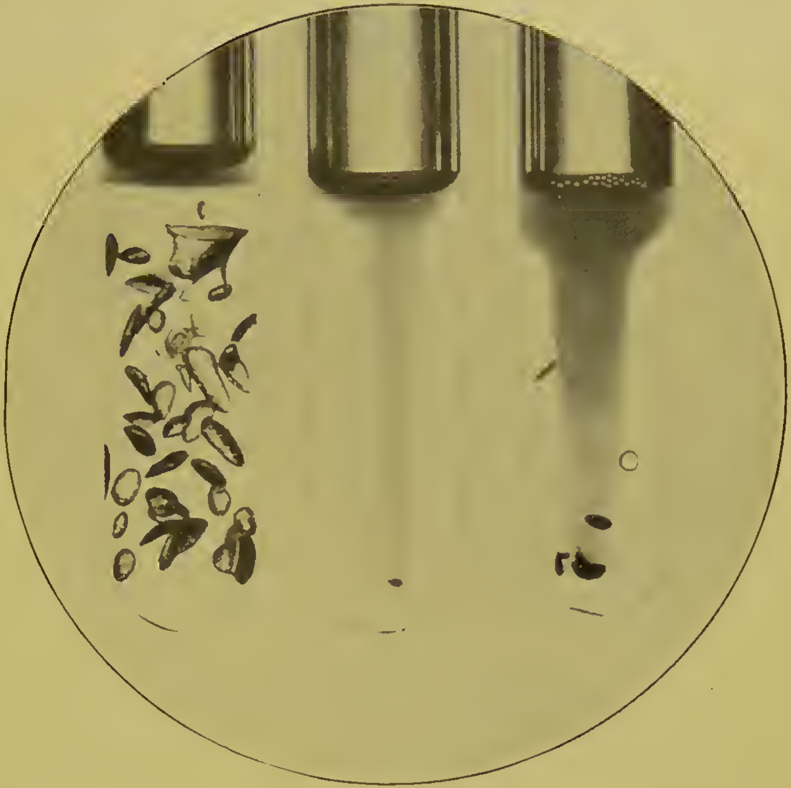

FIG. V.

"Sewage proteus." About natural size.
(a) Gelatine "shake" culture. 24 hours' growth at 20° C.
(b) Gelatine "stab" culture. 24 hours' growth at 20° C.
(c) Gelatine "stab" culture. 48 hours' growth at 20° C.

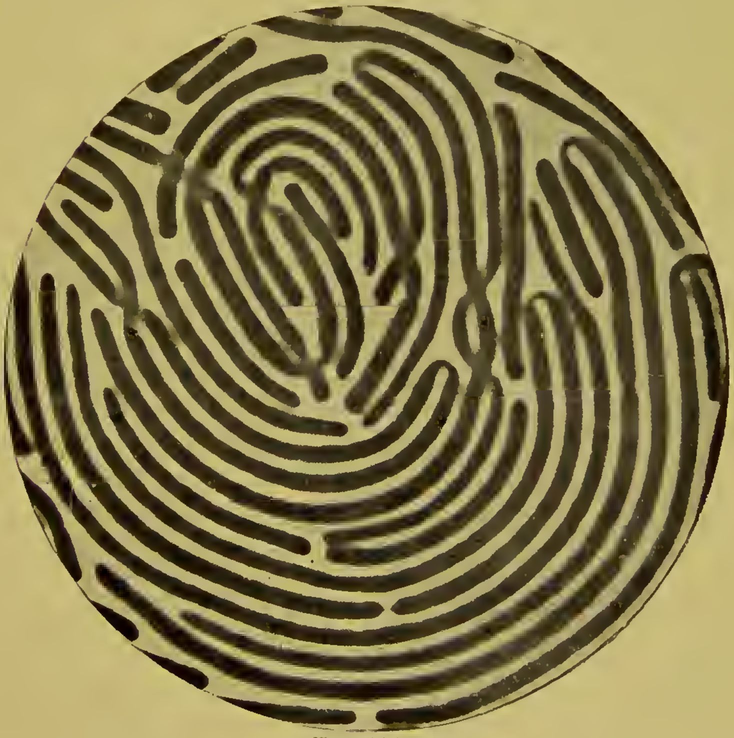

FIG. VI

Proteus vulgaris. Impression preparation from "swarming islands" on gelatine; 20 hours' growth at 20° C. × 3,000.

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The number of liquefying bacteria varied from 20,000 to 1,000,000 per cc. in the crude sewage, and from 470 to 60,000 per cc. in the filter effluent. In examining beds at Leeds worked on the Dibdin principle, it was noticed "that a multiplication of organisms occurs in the sewage during its passage from the entrance to the works on to the beds. The cause of this increase has not yet been ascertained, but the following table suggests that the addition of lime to the crude sewage tends to inhibit the multiplication of organisms" :—

Date, 1899.	*Crude Sewage.*	*Treatment.*	*Settled Sewage.*
27 Feb.—6 Mar. ...	2,518,500	Limed	2,746,030
6 Mar.—20 Mar. ...	2,597,950	Unlimed	6,109,000
20 Mar.—1 June ...	2,862,500	Limed	1,128,100

The dilutions employed in these experiments were as follows:— 1 in 1,000,000 for sludge, 1 in 100,000 and 50,000 for the crude sewages, and 1 in 10,000, 1,000, 500, and 100 for the filter effluents. The examination of the gelatine plates was made as follows: "The temperature of incubation was from 18 to 20°C. No fixed interval of time was selected for the incubation and counting, but they were carefully watched, and every endeavour made to count the colonies when the maximum number had developed. This was sometimes, but by no means always, rendered difficult by the number of liquefying colonies. The plate was counted by placing it upon a ruled disc, and a hand lens used to assist the operation. To eliminate, as far as possible, errors in counting, not only was the large number of 12 plates made from each sample, but the plates were divided into two batches . . . . . . and it was found that the figures obtained by the two observers, worked independently, varied but a very little, and showed a close correspondence."

The method employed for determining the liquefying organisms in the Chorley experiments has not been described, and presumably the counts were made from the ordinary gelatine plates. Clowes and Houston in their examination of the London sewage prepared extra "surface" plates for determining the liquefiers and they remark in their report that "although this method is the best one available, it must be remembered that some bacteria liquefy the gelatine so very slowly that they might readily escape being counted as liquefying germs under these conditions of experiment. This matters the less since bacteriologists are in the habit of classing some, at all events, of these bacteria as non-liquefiers."

The following is a list of some of the sewage bacteria which have been found by various observers :—

BACTERIA OCCURRING IN SEWAGE.

NOTE.—L, liquefying Gelatine; NL, not liquefying; SL, slightly liquefying.

Obligatory Anaerobes.

Spirillum rugula, L (very active, spore-bearing, gives rise to fæcal odour).
Sp. amyliferum (in absence of air acts as a vigorous ferment).
Bacillus enteritidis sporogenes. (Klein).
B. amylobacter, L (*Clostridium butyricum*).
B. butyricus (Botkin), L (gives much gas).

Facultative Anaerobes or Aerobes.

B. putrificus coli, NL (decomposes albuminous substances with liberation of ammonia, whether air is present or not).
Spirillum plicatile, serpens, undula, tenue, and *volutans*.
B. mycoides, L } *Proteus vulgaris*, L } Produce NH_3 from nitrogenous organic matter and denitrify.
B. fluorescens putridus (similar, produces trimethylamine).
B. fluorescens liquefaciens, L, and *non-liquefaciens*, NL.
Micrococcus ureæ, NL; *B. ureæ*, NL (convert urea into ammonium carbonate, the latter the most energetically). Flügge has also described a *M. ureæ liquefaciens*.
B. mesentericus, L (several varieties in London crude sewage).
Proteus mirabilis and Zenkeri, L.
B. megaterium, L; *liquefaciens*, L; *magnus, spinosus*.
Streptococcus liquefaciens coli, L, and *mirabilis*, NL.
B. saprogenes, I., II., III.; *pyogenes* and *coprogenes fetidus*.
B. acidi paralactici.
B. lactis ærogenes, NL (produces CO_2 and H).
B. coli communis, NL (produces much gas, mainly H).
B. subtilis, L is aerobic, and rapidly consumes oxygen.
Cladothrix dichotoma, L
Proteus sulphureus, L (produces H_2S and mercaptan).
B. sulphureum, L (liquefies gelatine and casein, produces H_2S).
Beggiatoa alba, (secretes granules of sulphur, formed, according to Winogradsky, by oxidation of H_2S, and finally turned into sulphuric acid by the plant).
The following forms reduce nitrates to nitrites:—B. *vermicularis, liquidus, ramosus, aquatilis* (grows luxuriantly in ammonia solutions), besides *mycoides and Proteus vulgaris*.
The following were found by Jordan in the sewage of St. Lawrence, Massachusetts:—*B. cloacæ*, L; *ubiquitus*, NL; *reticularis*, SL; *circulans*, L; *hyalinus*, L: all reducing nitrates. *B. superficialis*, SL, not reducing.
B. pyocyaneus was isolated by Houston from London crude sewage, and a culture proved to be extremely virulent. *Streptococci* and *Staphylococci* were also found.

Dr. Houston, describes some new species in London crude sewage, (*L.C.C. Report, 1899*), which after comparison with all others of their class, appear distinct.

B. mesentericus, two varieties, I and E. (Figs. 11 and 12 Plate IV.)

Variety I rapidly liquefies gelatine and blood serum, apparently peptonizes milk without subsequent coagulation, and has no reducing action on nitrates.

Variety E is longer, liquefies gelatine very slowly, liquefies blood serum fairly rapidly at 37° C., and produces a weak clot in milk which appears to subsequently redissolve; it reduces nitrate to nitrite in 24 hours at 37° C. From 10 to 30 spores per cc. exist in London sewage.

"*Sewage Proteus*," differing from *Proteus vulgaris*, *mirabilis* and *Zenkeri*, liquefies gelatine and serum, and peptonizes milk without coagulation. It was present in great numbers (usually over 100,000 per c.c.) in both crude sewage and effluents, and is suspected to be pathogenic, judging from some experiments on guinea-pigs. (Figs. 5, 6, and 7, Plates I. and II.)

B. frondosus, SL, a large bacillus, giving a leafy appearance at the edge of the colonies.

B. fusiformis, NL, with spindle-shaped spores and somewhat negative culture characters, seems to be a new species. (Fig. 10, Plate III.)

B. subtilissimus, NL, resembles a large micrococcus. (Fig. 13, Plate IV.)

B. subtilis, L. Several varieties occur in sewage. Two, A and B, are specially described in the Report.

B. membraneus patulus, SL, a very large species which forms long chains (Fig. 9, Plate III.)

B. capillareus, L, similar, but growing differently.

It is obvious that in such a fertile field as raw sewage new species are likely to be continually discovered.

ORGANISMS IN BACTERIA BEDS.

The organisms in anaerobic beds are chiefly bacilli, but cocci are not absent; the "clostridium forms" are very numerous, meaning such bacilli as develop spores in the middle, so that, owing to the bulging there and tapering of the ends, figures of a distinctly spindle shape are produced. This is characteristic of several species that are obligatory anaerobes, such as *Clostridium fœtidum*, which liquefies gelatine and develops an odorous gas, and *Clostridium butyricum* or *Bacillus amylobacter*. The latter on account of its importance and its wide distribution requires a special description. Prazmovsky, who first studied its characters, found it in almost all animal and vegetable matters decomposing in absence of air, while Nothnagel discovered it continually in fæces. The specific name "amylobacter" (*amylum*, starch) was derived from its being coloured blue by iodine. It liquefies both albuminoids and carbohydrates like cellulose, producing butyric acid and gases, chiefly hydrogen, carbonic acid and methane.

The Sutton beds were seeded at first with a culture of *Micrococcus candicans*, obtained by Dibdin from his coke breeze filters, but we now know that such seeding is unnecessary, as the mixed "flora" of sewage does not allow of the development of a pure culture of any specific organism. When zonal filters are used a natural differentiation of the organisms occurs. For instance, in well aerated filtering trays the absence of nitrites shows that the organisms producing these compounds from ammonia are absent, unless the filtrate is so far free from ammonia that they might be present, but inactive, from want of food supply.

ORGANISMS IN OXIDIZING FILTERS.

At this stage, if the working be efficient and the aeration thorough, the organisms which are exclusively anaerobic will disappear, while others will be reduced in numbers and replaced by new varieties including those which produce nitrites and nitrates.

Their action, which is similar to that occurring in soils, was first studied by Müntz and Schloesing in 1877, who proved that soil sterilized by heat, or by antiseptics such as chloroform, would not nitrify, that the organic matter must be first converted into ammonia and that certain conditions were necessary. Warington, Müller, Marie Davy, Heraeus, Munro, and others, elaborately investigated the subject, but failed to discover the specific organisms. These were first isolated and described by Winogradsky and P. Frankland in 1890, the former growing them in media almost absolutely free from organic matter. Kühne afterwards found that they were easily cultivated on *silica jelly* (p. 53), and others have since succeeded in acclimatizing them on agar plates prepared by Beyerinck's method.

Nitrosomonas (Winogradsky) oxidizes ammonia to nitrite, requiring no organic matter for its nutrition, as it assimilates carbon from acid carbonates. It appears as circular corpuscles less than 1 μ in diam., and sometimes as oval cocci.* The organisms from different parts of the world appear to be the same.†

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* *Warington, Proc. Chem. Soc.*, 1891, 484.

† *Burri and Stutzer, Chem. Centr.*, 1896, ii, 113.

PLATE II.

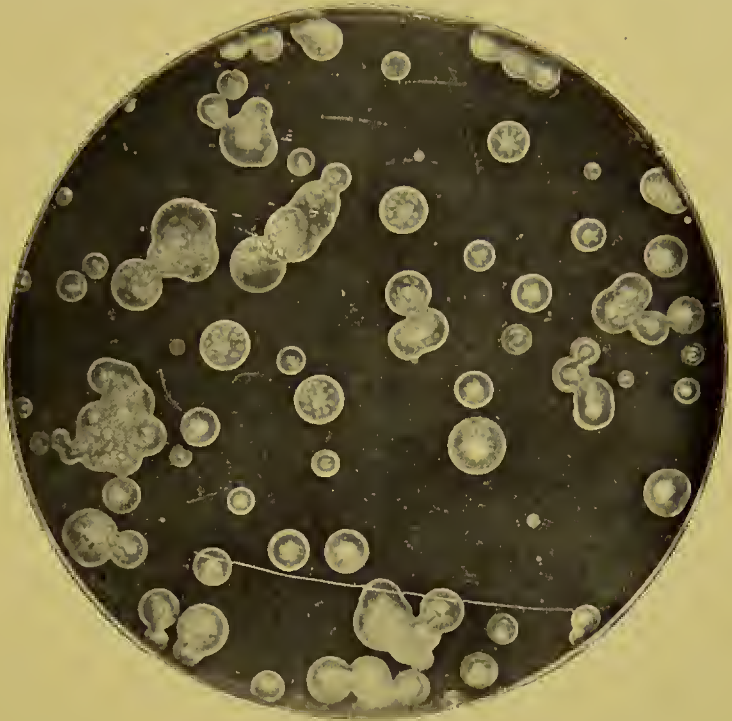

FIG. VII.

"Sewage proteus." Gelatine plate culture, two days' growth at 20° C., about natural size

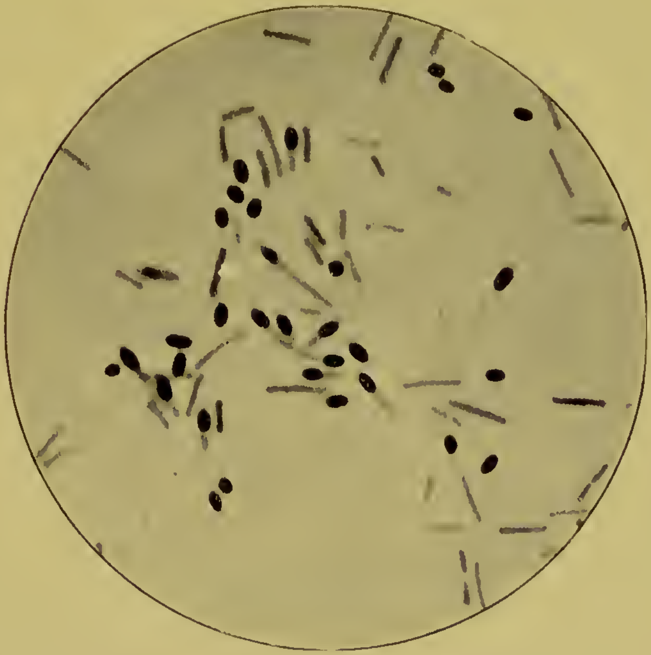

FIG. VIII.

B. enteritidis sporogenes (Klein). Microscopic double-stained preparation from a serum culture, showing spores × 2,000.

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Nitrobacter (Winogradsky), was isolated by P. Frankland by dilution from ammoniacal broth, as a bacillo-coccus which refused to grow in gelatine; but as it is unable to oxidize ammonia, the best medium for its growth is an inorganic solution, containing potassium nitrite and an acid carbonate. Omeliansky has recently confirmed the fact that both types of organisms are necessary to convert ammonia to nitrate, nitrite being an intermediate state (see p. 76).

Nitrification in filter beds will be considerably promoted by the organic matter present being greatly reduced in quantity, and the number of organisms producing ammonia should consequently diminish if this work has been done at an earlier stage. Thus at present in the working of the Crossness beds, the numbers reported per c.c. are:—

	Sewage	Effluent.
Gelatine plates at 20° C.	{6,400,000 3,670,000}	1,170,000 1,260,000
Agar plates at 37° C.	4,100,000	1,630,000

But the mere counting of the number of bacteria furnishes little information of the character of an effluent, as is shown by the following observations:—

(1) Meade Bolton and others have proved that some organisms commonly occurring in water, such as *Micrococcus aquatilis* and *B. erythrosporus*, can multiply enormously even in sterilized distilled water free from almost every particle of organic matter.

(2) The nitrifying organisms will live in the absence of all organic matter, and will not grow in the ordinary culture media, hence would be entirely omitted in the ordinary counting.

(3) During the purification, carbonic acid is produced in considerable quantity. This gas is inimical to a large number of bacteria.

OTHER ORGANISMS WHICH EFFECT PURIFICATION.

Besides bacteria in sewage, there are generally found many organisms of a higher grade. Water worms, such as Anguillula and Nais are stopped or killed in efficient purification; in fact, one of the causes that calls for an anaerobic stage is that these animals require oxygen, and perish rapidly under the air-free conditions. At the same time their preliminary agency in consuming and breaking down the larger *débris* is almost certainly of value.

Infusoria and other minute animals assist in the work of purification by acting as scavengers; their presence in vigorous activity is a proof of good aeration. Amœbæ and other protozoa on the other hand require scarcely any oxygen; I have even found them in small numbers in the sediment of the Exeter septic tank, which is practically anaerobic. They also must act usefully in attacking nitrogenous matter.

Algæ and water plants assist in the purification of an effluent by the nascent oxygen which they disengage from their green parts. They can also absorb by their roots and white parts ammonia and putrescent nitrogenous matters; they require, of course, clearing out at intervals to prevent the decayed portions from reversing the process.

SURVIVAL OF PATHOGENIC ORGANISMS.

This important point was raised at the Exeter Local Government Board Inquiry, referring to the pathogenicity of the product after anaerobic treatment, since it has been suggested that, whilst cultivating the bacteria necessary for the destruction of the organic matter in sewage, the pathogenic organisms present in the crude sewage will not only survive but may possibly multiply, and so cause the effluent to be dangerous to health. It is important, however, to remember that the bacterial processes are not novel, but are identical with those which obtain in nature, so that effluents from sewage farms are strictly comparable with filtrates obtained after either a "coarse bed" or a tank treatment.

Mr. Groves, in evidence before the London Water Commission, 1899, hoped that the Local Government Board would not depart from their past position with regard to land treatment, as from the typhoid statistics for London, he argued that the present method of dealing with sewage was satisfactory. Although with any new scheme it is difficult to obtain direct evidence as to its ultimate effect upon a river water which is subsequently to be used as a drinking supply, one must recollect that under existing circumstances the removal of all kinds of bacteria from the river water is attempted by those who desire to use such water for drinking purposes, so that, even assuming that bacterial systems tend to increase the bacteria in the river, they do not make any new departure necessitating a reconsideration of our methods of water purification. Even if an anaerobic treatment *alone* resulted in an effluent which possessed toxic properties disastrous to a small river, it must be recollected that no process is at present suggested which does not involve a full and efficient aerating filtration as a final method of purification, and it is the pathogenicity of such filtrates upon which information is wanted. Satisfactory evidence on most of the systems is now available, from which, I think, we are justified in concluding that, even if towns on a river like the Thames adopted bacterial schemes, the pathogenicity of the London water supply would not be adversely affected. With intermittent fine-bed filters following coarse-bed or chemical treatment, as at Leeds and London, fish have lived in the filtrate.

At Exeter, Dr. Cartwright Wood examined the tank effluent, the filtrate, and the river water before and after admixture. Broth inoculated with these fluids and incubated for forty-eight hours had no effect upon rabbits or guinea-pigs when 2 c.c. was injected subcutaneously. When inoculated for eleven days, the tank effluent, and the water at Belle Isle, contaminated with the untreated town sewage, were found to be morbific, but the filtrate and the water at Salmon Pool Weir, some little distance below the town, contained so little morbific material of any kind that even with this severe test both kinds of animals remained alive and perfectly well. Dr. Woodhead in his report concludes "that none of the organisms found in the tank effluent are themselves capable, in the quantities present or in which they can grow even in broth, of setting up any morbid changes."

With regard to typhoid fever, Lawes and Andrews some years ago showed that some liquefying organisms have a germicidal effect upon typhoid bacilli, so that their sojourn in a septic tank, or their arrest in an anaerobic upward filter, with such organisms diminishes instead of increases their chances of survival. Dr. Pickard, of Exeter, has proved this fact again experimentally by introducing an emulsion of the typhoid bacilli into a septic tank, when he found that instead of increasing they rapidly diminished, until after fourteen days less than 1 per cent. of the number introduced were surviving. The same investigation also proved that filtration was even more efficient in removing typhoid bacilli, as he found that filtration, as conducted at Exeter, removed about 90 per cent. of typhoid bacilli from sewage inoculated with this organism, and that subsequent filtration of tank effluent containing no typhoid through the same filter yielded filtrates containing only about 1 per cent. of the bacilli introduced in the first filtration, showing that the environment was unsuitable for their development if their absence from the first filtrate was due only to a straining action.

Dr. Houston with the Ducat filter has shown that with sewage containing 1,200,000 *B. coli* per c.c. a filtrate is obtained which contained no colonies resembling this organism in this quantity; and that sewage containing between 1,000 to 10,000 spores of *B. enteritidis sporogenes* per c.c. contained after filtration less than 10 per c.c., whilst the aerobic bacteria causing liquefaction of gelatine were likewise reduced from 22 to less than 1 per unit.

In my own work I have proved that the spores of *B. enteritidis sporogenes* survive, as might be expected, the septic tank treatment, but Houston has shown, as stated above, that 99 per cent. can be removed if the tank be followed by a well aerated filter. Before this evidence of the comparatively innocuous character of the filtrates from bacterial systems was available, I pointed out that subsequent chemical treatment could be used for sterilizing the filtrate if necessary. Such reagents as may be conveniently employed may be called "finishers," as when employed the resulting purified sewage is satisfactory both from the chemical and bacterial points of view. Chlorine is one of such reagents, and the late Dr. Kanthack established the fact that with one grain of free chlorine to four gallons of the tank effluent or to five of filtrate, with a contact of about five minutes, the number of bacteria can be reduced from any number (even millions) that may be present to 10 to 50 per cubic centimetre, and that no pathogenic organisms were found in any of the numerous samples of Maidenhead sewage finished in this way. I found at the same inquiry that on adding 1·77 parts of available chlorine per 100,000, although about half the amount immediately combines with any organic matter present, if the aerating filter has not worked efficiently, the micro-organisms by contact with the remainder are gradually killed, so that plate cultivations of such sewage taken after fourteen minutes showed no growth with 3½ days' incubation.

In the recent report of the London County Council, October, 1899, Dr. Houston has specially studied the possibility of the survival of pathogenic organisms after passage through bacterial filter beds, and from his investigation of the intermittent filters under experiment, he summarizes his opinion as follows:

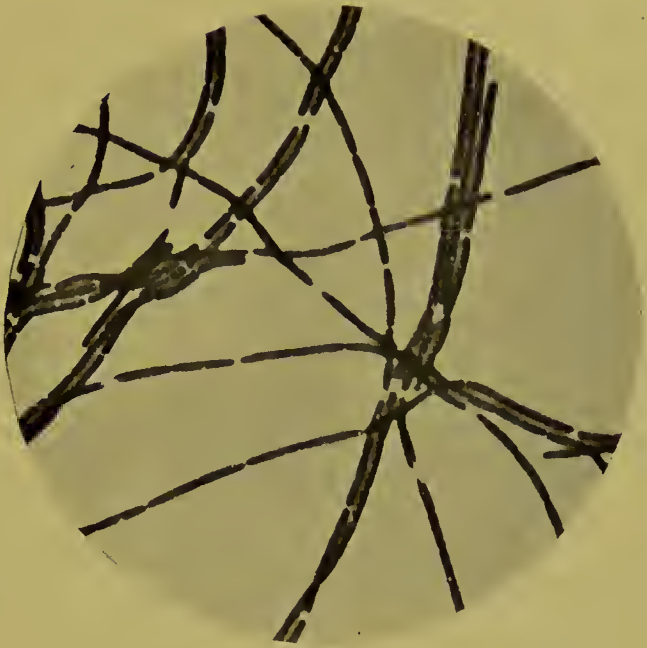

FIG. IX.

B. membraneus patulus. Impression preparation from a gelatine plate culture × 1000.

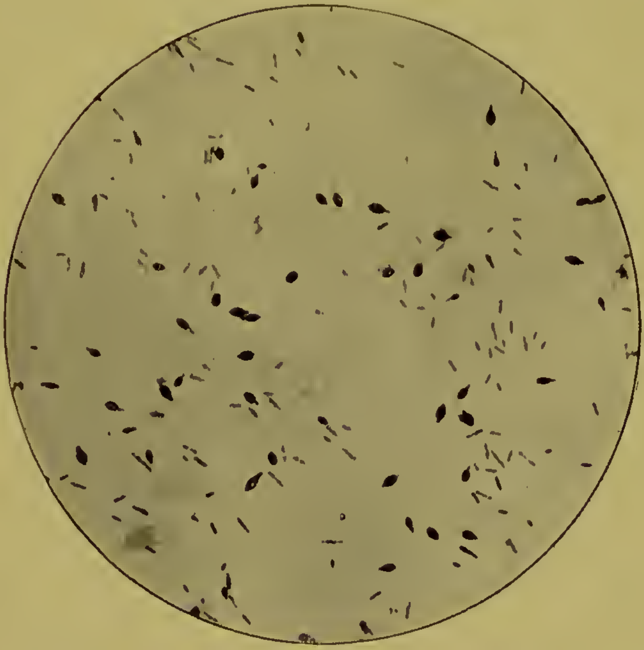

FIG. X.

B. fusiformis. Microscopic double-stained preparation, showing spores × 1000.

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> "It is to be noted in the first place that the biological treatment of sewage is conducted *under control*; secondly, that the process always gradually secures the destruction of the pabulum on which bacteria feed, and hence leads to their death; thirdly, that the balance of evidence points to the probability that some, at all events, of the pathogenic organisms are crowded out in the struggle for existence in a nutritive medium containing a mixed bacterial flora, their vitality being weakened or destroyed by the enzymes of the saprophytic species; fourthly, that while it is true that bacteria produce poisonous substances in their growth, it also is true that their chemical poisons are toxic in proportion to the dose, and, moreover, are highly unstable and readily break down into their elementary and innocuous constituents; and, lastly, that in some cases it may not be necessary to attempt the complete purification of the sewage, the solution of the suspended matters and partial destruction of the putrescible matter in solution being all that is urgently called for, as, for example, where the effluent is of relatively small bulk and is turned into a stream the water of which is not used for domestic purposes (as is the case in the lower Thames) or else when the effluent is to be subsequently treated by land irrigation."

He wishes it to be distinctly understood that he does not imply that such organisms as the *typhoid bacillus* or the *cholera vibrio* would *necessarily* lose their vitality, or even suffer a diminution in virulence under the conditions prevailing in a biological filter. In the absence of actual experiments with the particular sewage in question, he is not prepared to say more than that he believes that if these germs did gain access to the sewage they would suffer diminution in numbers primarily in the sewers, and secondarily in the coke-beds.

Dr. Houston, early in 1898, isolated from Thames mud four organisms, named by him *B. typhosus simulans* a, b, c, d, which differed from the true typhoid organism in failing to sediment with typhoid serum and in possessing a less number of flagellæ. They might, therefore, possibly be degenerate varieties of active *typhosus* caused by prolonged existence in sewage-polluted water. Dr. Horrocks has recently* studied the behaviour of the *B. typhosus* in sewage, and concludes that the bacillus will usually be found alive after 60 days immersion in strong and diluted sewage containing its usual toxines and salts, but freed from other living organisms. The power of sedimentation will be unchanged, but the colonies may present a dark granular crumpled appearance and the bacillus will show diminished resistance to carbolic acid.

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* J., San. Inst., 1899.

When, however, he employed unsterilized sewage, he failed to obtain any characteristic evidence of their survival after 14 days, and consequently it may be inferred that the life of the bacillus in unsterilized sewage is much shorter than would be imagined from the results obtained with sterile sewage.

Among the organisms which can be easily identified as directly derived from sewage, and which, if not themselves actually pathogenic, are associated with organisms causing disease, the *B. enteritidis sporogenes* of Klein, (Fig. 8, Plate II.), and *B. coli communis* are the most important. Dr. Houston, in the report already quoted, has examined the effluents from the coke-beds at Crossness, with a view to studying the survival of these organisms.

In comparing the cultures, no distinct difference could be made out, as regards the species of microbes, between the cultivations made from the crude sewage and those made from the effluents.

As regards the crude sewage and the effluents from the 4ft. bed, he noted that the number of spores of *B. enteritidis* varied from 10 to 1,000 per cc. In the case of both the 6ft. coke-bed effluent and the effluent from the laboratory vessel, the numbers were found to vary from 10 to 100 per cc., but there may have been more spores present, as the minimum amount of the liquid added to the milk-tubes was 0·01 cc. He continues :—

> "Judging the results as a whole, it cannot be said that the biological processes at work in the coke-beds produced any significant alteration in the number of spores of this pathogenic anaerobe. This is the less to be regretted since the effluents are discharged into a large tidal river below locks, the water of which is not used for drinking purposes. Still it is to be thought of that the cultures of *B. enteritidis sporogenes* are extremely virulent, and that Dr. Klein's results seem to prove that this anaerobe may be causally related to acute diarrhœa. At all events, it is highly important from a practical as well as from a scientific point of view to continue these observations on the number of spores of *B. enteritidis* in crude sewage and in the effluents from the coke-beds."

On the other hand, in a preliminary Report to the Royal Commission, Prof. Boyce, from experiments with this organism, concludes as follows :—

> "Filtration has a marked effect on keeping back this bacillus, especially when combined with precipitation. It was not found in the filter effluent from the septic tank at Manchester, nor in the pure filter effluent at Chorley or Oldham. It was, however, obtained in the former by filtering a quantity through a porcelain filter and subsequently scraping the surface. The addition of lime and copperas does not appear to have much effect on this bacillus."

> "The method for detecting the presence of the spores of the bacillus is as follows—Dilute 1 part of crude sewage or of effluent, as the case may be, with 99 parts of sterile water; of this dilution add 1·0, 0·1, and 0·01 c.c. severally to three sterile milk tubes. Heat the tubes to 80°C. for ten minutes, and cultivate anaerobically by Buchner's method at a temperature of 37°C. In certain cases it is necessary to add as much as 0·1 c.c. of the crude sewage or effluent directly to the milk tube. When *B. enteritidis* is present the casein is precipitated, the whey remains nearly colourless, and there is a marked development of gas. These changes in the milk commonly take place in less than 24 hours. A guinea-pig inoculated subcutaneously with 1 c.c. of the whey, usually dies in less than 24 hours, and presents on post-mortem examination appearances which are typical of enteritidis (extensive gangrene, sanguineous exudation full of bacilli, etc.)"

Bacillus coli communis, which is present in London crude sewage in numbers exceeding 100,000 per c.c. is one of the most abundant and characteristic of sewage bacteria, and survives the processes at work in these biological filters at Crossness. Even in so minute a quantity as $\frac{1}{100000}$ c.c. of this crude sewage, *B. coli* and closely allied forms were present, so that its identification leads to a process of great delicacy for the detection of pollution of water with minimum quantities of sewage.

Houston points out that *B. coli* is abundant everywhere, that it multiplies outside the animal body, that it is present in the intestinal contents not only of human beings but of the higher mammals and birds, and that, therefore, its value as an indication of pollution of water of possibly dangerous sort is *nil.* The fact remains that in crude sewage *B. coli* is present in numbers exceeding 100,000 per c.c., and is absent, or present in but few numbers in a corresponding amount of a water free from suspicion of recent pollution. Moreover, if this organism multiplies outside the animal body under favourable conditions, it also loses its vitality under unfavourable conditions, and we have yet to learn that the excrement of healthy, much less of diseased, mammals and birds is altogether harmless to man.

The *Bacillus coli* may be pathogenic, but can hardly be considered pathogenic in the ordinary sense of the term. Its presence serves rather as an index of the possible presence of other and more objectionable kinds of bacteria.

In searching for *B. coli* in the crude sewage and in the effluents, Dr. Houston adopted the following plan—10 c.c. of sterile gelatine, contained in a test tube, were melted, 0·1 c.c. of five per cent. phenol added, and then the gelatine was poured into a Petri's capsule and allowed to become quite solid. 0·1 c.c. of diluted sewage, or else of effluent (1 : 10,000) was next added and spread over the entire surface of the gelatine with a platinum spreader. Colonies which were typical of *B. coli* in their microscopical appearance and in the manner of their growth were then subcultured in broth (for diffuse cloudiness and indol reaction), in litmus milk (for acidity and clotting), and in gelatine shake culture (for gas formation). It was not, however, found possible in all of the experiments to apply all of these tests, although, in the majority of cases, the gas test in gelatine was applied.

B. coli produces no liquefaction of gelatine or blood serum, but clots milk in 24 hours at 37°C. No spores have been detected.

According to Gabriel Roux, *B. coli* cultivated on artichoke gives rise to an intense green coloration; when cultivated in a medium containing quinol (hydroquinone) a brown coloration is developed.*

In concluding, Dr. Houston adds the following comments on the presence of this organism in the effluents :—

> "Judging the experiments as a whole, it cannot be said that the biological processes at work in the coke-beds effected any marked alteration in the number of *B. coli*. It must not, however, be too lightly considered that this implies that the effluent was necessarily of an offensive and putrescible character. *B. coli* and other putrefactive bacteria no doubt work in the direction of purifying the sewage, and their presence in the effluent might only mean that the purification had not been carried sufficiently far to allow of a decrease in their numbers, owing to the incomplete reduction of the organic matters on which they feed and which allow of their continued multiplication. Yet, when this has been said, it must also be admitted that the passage of an aerobic non-spore-forming bacillus typical of excremental matters through the coke-beds, in practically unaltered numbers, is not a desirable state of things. It is true that *B. coli* is not pathogenic in the ordinary meaning of the word, but its presence in the effluents implies the possible presence of other bacteria—it might be of a dangerous sort. Still, on the whole it may be said that the balance of evidence points to pathogenic aerobic bacteria being liable to be crowded out in the struggle for existence in a nutrient fluid containing a mixed bacterial flora and one rich in saprophytic micro-organisms. Lastly, it must be remembered that the effluent is discharged into a large tidal river at a point far below the lowest 'intake' of water for waterworks purposes. Moreover, the Thames before it reaches the Outfalls of the Sewage Works is already grossly polluted with excremental matters."

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* *Compt. Rend.* 1899, cxxviii. 693.

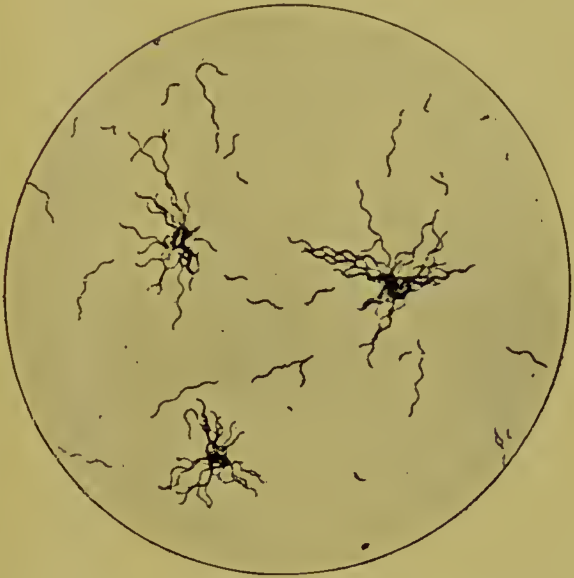

FIG. XI.

B. mesentericus. Sewage variety I. Microscopic preparation stained by V. Ermengem's method, showing numerous flagella; from a 20 hours' agar culture at 20° C. × 1,000.

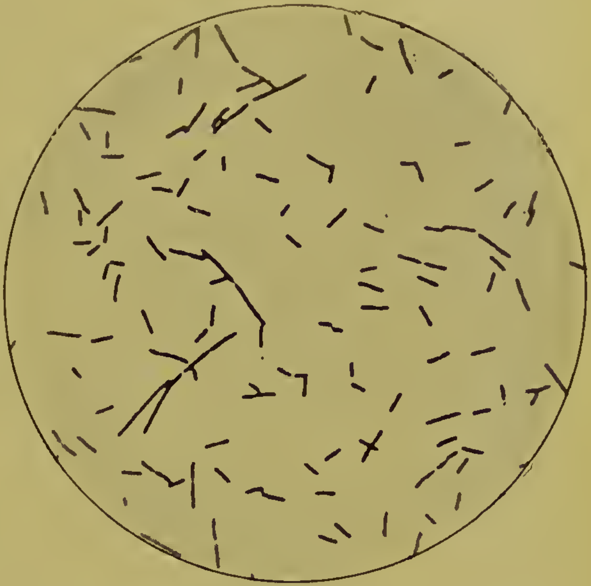

FIG. XII.

B. mesentericus. Sewage variety E. Microscopic preparation from a 20 hours' agar culture at 20° C. × 1,000.

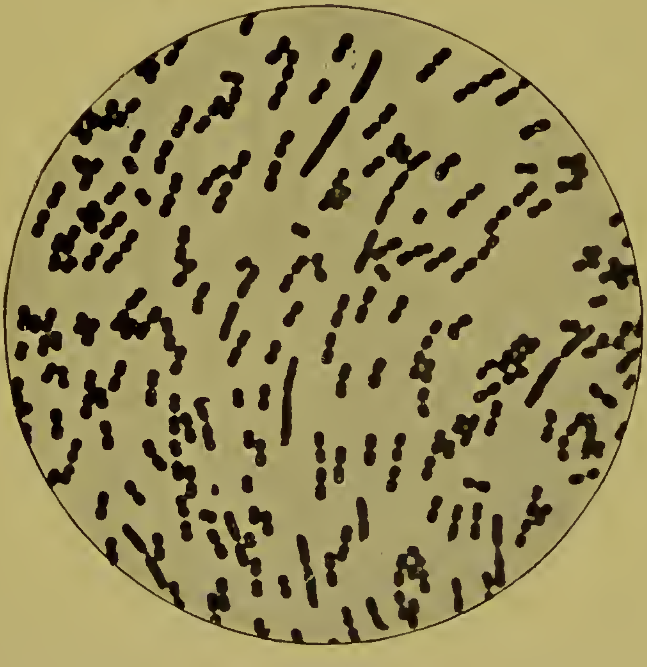

FIG. XIII

B. subtilissimus. Impression preparation from a gelatine plate culture × 1,000.

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I have also myself specially examined the effluents from the Scott Moncrieff filters at Caterham with a view to ascertaining whether the sewage organisms survived the oxidizing influence to which they were subjected in their passage through the nitrifying trays, and I found that the number of organisms capable of growing on carbolised gelatine surface plates, amongst which the *B. coli communis* is found, were reduced from 2,180,000 per cc. to 100,000 in the filtrate from filter C, to 50,000 in that from D, and 80,000 in the filtrate from F, so that whilst the least efficient of the filters removed 95 per cent. of these organisms, the best filter D removes 98·5 per cent.

I further found that although the addition of ·0001 cc. of the tank effluent to a broth tube and incubation at blood heat for four days produced indol, the same dilution of the filtrate from D gave no turbidity or indol, whilst the filtrates from C and F although producing turbidity, also failed to give any indol reaction.

The survival of spores of *B. enteritidis* is no less interesting, and may be best seen from the following table, where + indicates the presence of such spores, and – their absence.

	Tank Effluent.	Filtrates.		
		C.	D.	F.
.01 c.c.	+	+	–	+
.001 c.c.	+	+	–	–
.002 c.c.	+	+	–	+
.0001 c.c.	–	–	–	–

The nitric nitrogen and the ammoniacal nitrogen present in the filtrates when the bacterial samples were collected, are shown in the following table :—

	Tank Effluent.	Filtrates.		
		C.	D.	F.
Nitric Nitrogen	*Nil*:	5.48	11.6	10.96
Ammoniacal Nitrogen ...	12.3	4.56	2.05	3.28

It may therefore be concluded that the greater the aeration and nitrification, the less is the possibility of the survival of pathogenic organisms.

CHAPTER V.

Chemical Changes produced by Bacteria—Hydrolysis and Oxidation—Nature and Order of the Reactions—Symbiosis and Antagonism—Enzymes—Classes of Transformations—Utilization of Gases Produced—Sources of Energy—Nitrosification, Nitrification, and Denitrification.

When one looks back to a period of 30 years ago, it will be recollected that at that time methods of upward filtration were suggested in the place of chemical precipitation, and the results obtained were of such a satisfactory character that it is difficult to understand how authorities almost universally adopted the chemical treatment. There can be no doubt that in slow upward filtration of sewage the arrested suspended matter slowly disappears just in the same way as when the solid matter of sewage, after being removed by straining or by chemical precipitation, subsequently disappears when dug into the ground or buried beneath the surface.

Similar changes take place in mud banks in estuaries, below the surface of the water, and the conversion of organic matter of vegetable or animal origin at the bottom of a stagnant pool into harmless gases is of the same nature.

Such transformations are of such a subtle character that for the most part they have escaped attention, and yet, without doubt, they are as important as those more prominent ones which take place in the presence of light and air.

It would seem that in nearly all cases of destruction of organic matter this preliminary disintegration takes place before the final oxidation of the elements. But solid organic matter capable of undergoing change, even in the presence of air can only oxidize directly on its surface, whereas in a rotten apple or cheese, changes take place beneath the surface, which pave the way for the final oxidation.

Organic matter in solution similarly seldom oxidizes directly to its final oxidized products, but passes through intermediate conditions until the more complex organic forms are resolved into others of more simple structure, and these are subsequently burnt up to the stable oxidized compounds—water and carbonic acid.

It is difficult to give a single name to these phenomena; the older terms "decay," "putrefaction," and "eremacausis" did not sufficiently differentiate between them and the combustion which follows so closely. The term "bacteriolysis" has been suggested, and it seems a useful one to retain. When the action is effected by chemical agents, the term "hydrolysis" has already been used by chemists for such breaking down of organic matter. Other cases, in which the decomposition takes place without any absorption of water, may be grouped under the general term "fermentation." In some of these oxidation is simulated, since the organic matter is partly converted into oxidized compounds. The oxygen, however, in such products is not derived from the air, but is that which was originally present in the organic matter or water taking part in the reaction.

Thus to take a specific example: albumen contains the elements carbon, hydrogen, nitrogen, and oxygen in the ratio represented by the empirical formula $C_8H_{13}N_2O_3$. An anaerobic change, due to hydrolysis, could be expressed thus:—

$$4\,C_8H_{13}N_2O_3 + 14\,H_2O = 4\,N_2 + 19\,CH_4 + 13\,CO_2 + 2H_2$$

Such an ideal change would result in the production of all the gases which are commonly met with in these decompositions and leave no soluble organic matter for oxidation. Non-nitrogenous substances like cellulose and woody fibre can similarly break down into starch, sugar, &c., and in presence of yeast into carbonic acid and alcohol. In most natural anaerobic changes of this character it is found however that there are residual compounds containing nitrogen, of a humus-like character, which have been little examined. These compounds are very stable, and resist chemical action. In peaty soils they seem to exist in appreciable quantity. Adeney has noticed their formation in his experiments, and in the Exeter septic tank the black suspended matter is of similar character. That this stable nitrogenous matter does slowly disintegrate is shown from the experiments at Harpenden, where crops have grown on unmanured land for long periods, under such conditions that it is difficult to ascribe any other source for their nitrogen.

I was one of the first to point out that when these changes are brought about by organisms which are facultative anaerobes, the breaking down of gelatine to albumoses, ammonia, peptones, etc., is not accompanied by any absorption of oxygen, or the formation of any oxidized products, and it is, moreover, obvious that in the natural process of digestion, solid foods, both nitrogenous and non-nitrogenous, are digested in the stomach and intestines before the products are absorbed by the blood and so rendered useful by oxidation.

The amount of oxygen required to render inoffensive a unit weight of the substances occurring in sewage, of course depends on the species of the bacteria which are acting, as they determine whether the result should be a complete burning to CO_2, H_2O, and N, or a partial decomposition to equally harmless compounds like NH_3 and CH_4. Thus *Streptococcus longus* liquefies fibrin to ammonia, methylamine, and trimethylamine, and leaves in solution tyrosine, leucine, fatty acids, succinic acid, collidine, and peptones.*

Elastin, with anaerobic organisms, evolves carbonic acid, hydrogen, methane, and nitrogen, whilst the sulphur remains in solution as mercaptan, and is not evolved as sulphuretted hydrogen.†

Grass similarly evolves carbonic acid and nitrogen, under the action of *B. subtilis* and other organisms. *B. mycoides* also acts upon the carbohydrates in grass, ferments glucose to inactive lactic acid, and hydrolyses cane-sugar, maltose, and glycogen.‡

The gases found in the septic tank at Exeter are as follows :—

	Per Cent.	By Volume.
CO_2	0·3	0.6
CH_4	20·3	24·4
H	18·2	36·4
N	61·2	38·6
	100·0	100·0

Wood and Wilcox have shown that there are similar gases produced by *Bacterium furfuris* in the manufacture of leather This bacterium does not attack cellulose, but only starch and nitrogenous matter. They found a sample of the gas evolved to contain :—

CO_2 and traces of H_2S	25·2 per cent.
Oxygen ...	2.1 ,,
Hydrogen	46·7 ,,
Nitrogen...	26.0 ,,

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* Emmerlich, Ber. 1897, 30, 1863.

† Zoja. Zeit, Physiol. Chem., 1897, 23, 236.

‡ Emmerlich, Ber., 1897, 30, 1896.

while formic, acetic, butyric, and lactic acids were produced; these in sewage would combine with ammonia.

Much of the carbonic acid dissolves in the water, as does also the ammonia formed, whilst the hydrogen, from its easy diffusibility, escapes from the tank more rapidly than the heavier gases. No sulphuretted hydrogen has been found in the septic tank, the changes, therefore, are similar to those which take place in the anaerobic fermentation of elastin.

The following table shows the weight of oxygen required to oxidize some typical organic compounds completely to their final stable products :—

Substance.	Empirical Formula.	Percentage composition.				Oxygen required by one part to convert it into :	
		C	H	N	O	CO_2, H_2O, and N.	CO_2, NH_3 and H_2O.
Albumen ...	$C_8H_{13}N_2O_3$?	53·4	7·1	15·8	23·7	1·754	1·48
Gelatine	...	50	6·6	15·3	25·1	1·61	1·33
Starch, cellulose, and woody fibre	$C_6H_{10}O_5$	44	6·2	...	49·4	1·184	1·184
Ammonium amido-acetate (ammonium salt of glycocine)	$C_2H_8N_2O_2$	26·1	8·76	30·43	34·78	1·043	0·53
Urea	CH_4N_2O	20	6·7	46·7	2·66	0·803	0

The second important change necessary for the complete destruction of the organic matter, involves the essential that free or available oxygen, either from the air or oxidized compounds, shall be present. It has been customary in recent years in discussing the action which takes place in filter beds and in rivers, as well as beneath the surface of sewage farms, to call the phenomena "nitrification," but it is necessary to point out that oxidation of the organic carbon also takes place at this stage. The more general term "oxidation" is therefore more useful, and indicates more clearly what takes place in the final purification of a sewage effluent.

The experiments carried out by the Massachusetts Board of Health, and by the London County Council at Barking, have been directed almost entirely to the second and final stages in the treatment of sewage. In the experiments, with the acre filter bed, it will be recollected that only sewage which had been chemically treated or in which the solids and suspended matters had been removed, was used. It is also important in discussing this question to recollect that the anaerobic or hydrolytic change takes place very rapidly under favourable conditions, and that it is not unusual to find, especially in towns in which the sewers are old and tortuous, a crude sewage in which these preliminary disintegrating changes have taken place to a very considerable extent.

Anaerobic fermentation is called by the Germans *true putrefaction* (Faulniss), while aerobic is termed *mouldering* (Verwesung). It seems sufficient to recognize the first as a *hydrolytic*, and the second as an *oxidation* change.

It is easy to see, by calculation, that an average sewage from a water-closet town, with a water supply of, say, 25 gallons per head, should produce a sewage which, when fresh, should contain about 10 parts of organic nitrogen per 100,000, but one finds in the majority of cases the sewage of a town contains only from 1 to 2 parts of organic nitrogen, and in many cases less than this amount. This difference must be due to the very rapid breaking up of the organic matter present by the anaerobic changes described, and is accompanied by a corresponding increase in the ammonia from mere traces up to 8 parts per 100,000, less the loss which may be due to the evolution of free nitrogen gas and possibly oxides of nitrogen.

When fæcal and other solid matters are first discharged, the earliest changes must be aerobic, because of the free oxygen dissolved in the water and contained in the air. The effect is mainly the same as the *last* stage, *i.e.*, the organisms acting in a normal manner upon those simpler constituents like ammonia, which must obviously already exist in small quantities, and into which the process itself afterwards resolves the main ingredients of the sewage. Nitrates in small quantities are consequently often observed in discharges which are moderately fresh.

As soon as the free oxygen has been exhausted, these oxidation changes come to an end, and the bacteria which require air in part disappear, and in part remain quiescent to resume their functions at a later stage. On the other hand, the anaerobic organisms will commence to multiply, the nitrate will be reduced to nitrite and this to nitrogen, according to reactions we shall explain later, and the liquefaction and hydrolysis changes will proceed. This is the condition when the sewage arrives at the works, and the first, or anaerobic stage of the treatment proper, commences.

In the second stage aeration is to be encouraged as much as possible, so that the aerobic bacteria may act and ammonia and carbonic acid be produced with the help of some of the anaerobic forms.

In the third stage, with provision of a still larger quantity of oxygen, the nitrifying group will get rid of the remaining products.

We may summarise the order of the changes as follows :—

	Substances dealt with.	Characteristic products.
INITIAL.		
Transient aerobic changes by the oxygen of the water-supply rapidly passing to :—	Urea, ammonia, and easily decomposable matters.	
FIRST STAGE.		
Anaerobic liquefaction and preparation by hydrolysis.	Albuminous matters. Cellulose and fibre. Fats.	Soluble nitrogenous compounds. Phenol derivatives. Gases. Ammonia.
SECOND STAGE.		
Semi-anaerobic breaking down of the intermediate dissolved bodies.	Amido-compounds. Fatty acids. Dissolved residues. Phenolic bodies.	Ammonia. Nitrites. Gases.
THIRD STAGE.		
Complete aeration : nitrification.	Ammonia and carbonaceous residues.	CO_2, H_2O and nitrate.

In ordinary bacteria beds these reactions are often reversed and confused, according to the periods of filling or rest, which allow the different bacteria to act in the same filter.

As we have mentioned in the last chapter it is practically impossible to confine the bacterial action to one species, by seeding or otherwise, in view of the immensely varied character of the organisms that are present, nor would such a proceeding be advantageous. As we saw when discussing the disappearance of pathogenic bacteria by passing through cultivation beds, the crowding out of these special forms by the more numerous harmless varieties which thrive at ordinary temperatures, is an important part of natural purification.

At the same time it is necessary to be aware of the mutual relations of the predominant species in order to know whether we have healthy conditions. Organisms growing together either antagonise each other's development, or more rarely encourage it, or even are necessary to one another. Nencki calls the former case "enantibiosis," the latter "symbiosis." For the former conditions we may use the simpler word *antagonism*. Freudenreich and Sirotinin investigated the mutual influence of bacteria. They found, like other observers, that in mixed cultures certain species would develop rapidly, to be supplanted later by those of slower growth, so that the more vigorous organisms were not always the most useful. Some species actually prevented the growth of others by (1) exhausting their food, or (2) by excreting products which were injurious: the latter is true antagonism. Thus Freudenreich found that *B. pyogenes fetidus* (p. 58) prevented the growth of the cholera spirillum, that *Micrococcus roseus* similarly inhibited *M. tetragenus*, while *B. pyocyaneus*, *phosphorescens*, and *prodigiosus* caused a change in broth which prevented the growth of other species.

Garré demonstrated this antagonism by making streak cultures of various bacteria on gelatine plates, in parallel or intersecting lines.* Lewek inoculated gelatine or agar with equal numbers of different varieties, adjusted by counting and appropriate dilution.†

K. B. Lehmann draws the practical inference that in counting bacteria very dense plates should be avoided.

Symbiosis is the condition when two or more kinds of bacteria act together and effect decompositions which neither of them could do separately. Each may live independently, but they thrive better and more continuously in company than alone. Organisms of this kind are said to be *synergetic*. Lehmann states that some organisms ordinarily anaerobic can thrive on the admission of air if certain aerobes be also present, which is one reason accounting for the presence of anaerobes in oxidizing beds or filters.

The cause of symbiosis is generally found in each of the organisms taking one part in a sequence of chemical actions. Thus, Omelianski, by pure cultivations, explained some results that Adeney and others had previously noticed. Three organisms, *B. racemosus*, *nitrosomonas*, and *nitrobacter*, when added to bouillon converted the organic nitrogen of the latter into nitric acid, ammonia and nitrous acid being intermediate stages. The first of these organisms produces the ammonia from the organic nitrogen, the second converts it into nitrite, and the third the nitrite into nitrate. The first change requires no oxygen, the second change requires some oxygen, and the final change a still greater quantity. With a culture of the first two, nitrite and no nitrate was produced. With a mixture of *B. racemosus* and *nitrobacter*, ammonia was the only product, as the absence of the nitrite-forming organism prevented the conversion of the ammonia into food for the nitrifying organism. A mixture of the two last species failed to determine the decomposition of the original culture medium even after ten months.

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* *Corresp. für Schweizer Aertze*, 1887.

† *Centr. f. Bakt.*, vii., 107.

Otto Künnemann* also found that Burri and Stutzer's *B. denitrificans I.* is effective only in symbiosis with *B. coli*: the latter supplies it with its necessary ammoniacal food. Also, as Hugo Weissenberg† finds, *B. coli* reduces nitrate to nitrite, which in turn is denitrified by the organism I.

ENZYMES.

A great number of changes, most of them hydrolytic, are accomplished by the large class of organic substances termed "enzymes," which, though not living, are products of animal and vegetable life. These enzymes have been defined by Lehmann and Neumann as "chemical bodies, which in minimum amounts and without being used up are able to separate large amounts of complicated organic molecules into simpler, smaller, more soluble and diffusible molecules." The definition is not quite accurate, as the milk ferment, for instance, actually coagulates casein, or renders it insoluble, but it gives an idea of the immense power that these enzymes possess, and the economy of their use as distinguished from ordinary chemical or mechanical means. Their importance to us is shown by the fact that a large number of them are the products of bacteria or other fungi, and are powerful agents in their resolving action. By their means a bacillus is not only able to act in its immediate neighbourhood, but also at a considerable distance, through the soluble ferments it forms and disengages.

The enzymes are soluble nitrogenous bodies, which can be precipitated and rendered inert by strong alcohol, mercuric chloride, and by boiling. They can be separated from bacteria by filtration, when the soluble enzymes pass through, while the bacteria are retained. Other distinctions from the organisms which produce them are:—

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* *Landw. Versuchs Stat.*, 1898, 65.

† *Archiv f. Hygiene*, 1897, xxx. 3.

1. Enzymes can work at a greater range of temperature,—that is, are less susceptible to heat and cold than the living bacteria. Therefore, it is possible to find temperatures which will inhibit, if not kill, bacteria, without affecting enzymes.

2. Antiseptics, like chloroform, thymol, etc., which kill or inhibit bacteria, do not prevent enzymes from acting. Thus Salkowski* inoculated fibrin with putrefactive bacteria and kept it in chloroform water. It remained sterile for an unlimited time, but nevertheless underwent solution with the usual products, due to an enzyme secreted by the bacteria at first.

Dr. Armstrong† proposes the terms—*Zymosis* for fermentation by living organisms; and *Enzymosis* for change by enzymes or unorganized ferments.

The former class of changes would be *intracellular* or within the cell, under the immediate action of the protoplasm; the latter class would be external or *extracellular*; by such means bacteria are able to produce effects which are quite out of proportion to their size or numbers. Enzymes are formed not only by bacteria, but by moulds, larger fungi, and also by plants and animals, but have not as yet been prepared artificially. Their mode of action is still imperfectly understood: probably they act like some inorganic bodies by forming unstable compounds with portions of the organic molecule, which then break up, leaving the substance hydrolysed, and freeing the enzyme to act again.

As the enzymes are of such value, it will be useful to give a list of the more important; many of them, or their analogues, must occur in sewage, since the changes they produce are present. We may divide them into groups.

I. *Enzymes which break up albuminous bodies.* The ordinary digestive ferments, *pepsin*, *pancreatin*, etc., are of this class. Bodies identical or similar, are secreted by many bacteria, and Lehmann believes that the body which liquefies gelatine in cultivations is the same as *trypsin* from the pancreas. They form albumoses, then peptones. Papain is an example of a vegetable enzyme which hydrolyses nitrogenous matter. I found that the enzyme‡ produced by *Bacillus fluorescens liquefa-*

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* *Zeit. Phys. Chem.*, 1899, xxvii. 305.

† *Trans. Chem. Soc.*, June, 1890, p. 528.

‡ Rideal and Orchard, *Analyst*, Oct., 1897.

ciens, when separated from the organism by a Pasteur filter, is capable of causing liquefaction of gelatine. Professor Boyce has confirmed this observation, and has observed that *B. enteritidis sporogenes* forms a similar enzyme.

II. *Enzymes which attack carbohydrates. Diastase*, which dissolves starch, forming dextrine and sugar, is a type of a class of *amylases*, comprising *glucase*[*], *granulase*, *maltase*, and *dextrinase*, described as having slightly different functions. *Invertase* and *lactase* alter the sugars. *Zymase* (Buchner), from yeast and some other fungi, converts sugar into alcohol and CO_2. *Cytase*, which dissolves cellulose, we shall describe later.

III. *Enzymes which decompose fats. Lipase* (Hanriot), and others will also be further alluded to.

IV. *Special actions.* These are very numerous. Abelous and Gerard[†] have obtained from animal organisms an enzyme reducing nitrates to nitrites.

Enzyme changes like those by bacteria are arrested when the products reach a certain amount. This hindering of a reaction by the presence of the product of an enzyme change, with the possibility of attaining a point of equilibrium between a direct and inverse change, has been specially studied by Hill.[‡] As a representative instance he takes the conversion of maltose into glucose by *maltase*, an enzyme from yeast. With a 40 per cent. solution he shows that equilibrium is reached when 84 per cent. of the sugar is maltose and 16 per cent. glucose.

$$\left.\begin{array}{ccc}\text{Maltose} & \xrightarrow{\hspace{3em}} & \text{Glucose} \\ 84\% & \xleftarrow{\hspace{3em}} & 16\% \end{array}\right\} \text{in 40 per cent. solutions.}$$

In weaker solutions the equilibrium point for maltose increases, so that in a 2 per cent. sugar solution, it is almost completely converted. In a solution so dilute as a sewage the influence of the products would hardly be felt, so that the enzyme changes would proceed to completion. Still, the action is more energetic when the products are removed as formed, and the bacteria are supplied with fresh food.

The fermentations occurring in the first or hydrolytic part of the process may be chemically classified as follows :—

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[*] *Beyerinck Bied. Centr.*, 1896, xxv., 753.

[†] *Compt. Rend.*, cxxix., pp. 56 and 164.

[‡] *Jour. Chem. Soc.*, Aug., 1898.

1. The solution and decomposition of albuminous bodies.
2. The fermentation of urea.
3. The fermentation of the amido-compounds formed from the albuminous bodies.
4. The formation of organic acids, and the fermentation of their salts.
5. Cellulose or methane fermentations.
6. The fermentation of carbohydrates.
7. Decomposition of fats.
8. The formation of small quantities of sulphur compounds, like H_2S, mercaptan, etc. This, from the odour of the products, often attracts the most attention.

These, as a rule, are brought about by bacteria, mould and yeasts not being commonly found in sewage, indeed their presence, according to Andreasch, is distinctly prejudicial to normal bacterial action.

I. *Hydrolysis of Albuminous Bodies.* The putrefactive fermentation of albuminous bodies is caused by a large number of species, of which the forms from London sewage, mentioned in the last chapter, are among the most frequent. The first action is parallel to ordinary digestion, that is the so-called *peptonization*, or conversion into a soluble form. The peptones are then split up, amido-acids like leucin, tyrosin, etc., are formed, together with a number of substances of the aromatic group.

L. Geret and Martin Hahn* describe proteolytic enzymes existing in yeast and also in such bacteria as *Sarcina rosea*, *B. tuberculosis*, and *B. typhosus*, and state that they not only decompose and dissolve the albumen already present, but also attack additional quantities of albumen from other sources.

II. *The Fermentation of Urea.* Ordinarily, by the action of *B. ureæ* and *M. ureæ*, a simple and typical hydrolysis occurs, thus :—

$$CO(NH_2)_2 + H_2O = CO_2 + 2NH_3$$

The carbonic acid and ammonia combine to form carbonate of ammonium which dissolves, therefore none is evolved as gas, and no oxygen is required beyond that derived from the water, even for the bacteria, since these are facultatively anaerobic, *M. ureæ*, for example, growing equally well in oxygen and hydrogen, and we know that urine putrefies in closed bottles.

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* *Berichte*, 1899, xxxi., 2335.

Miquel found that several water-bacteria readily converted urea into ammonium carbonate, and that *M. ureæ* was constantly present in the atmosphere.

III. *The disposal of amido-compounds derived from albuminous bodies.* It will be seen from the table (p. 73) that either nitrogen or ammonia can be produced by bacterial action.

That both transformations of some of these bodies occur is proved by the composition of the gases from a closed tank as already given, and also by the liberation of H and CO_2 in anaerobic cultures. Thus Hugounenq and Doyon* found that under these conditions *B. coli communis* generated H and CO_2 (the gas bubbles), *B. tetani* also H and CO_2, *B. typhosus* N and CO_2.

Every eight parts by weight of oxygen absorbed from water would involve the liberation of an equivalent, or one part by weight of hydrogen, so that the weights, if increased by one-eighth, give the weight of water taking part in the hydrolysis. At present it is difficult to say whether the first or second of the transformations given in the last two columns of the table should be encouraged. As a matter of fact, both usually occur in practice.

It is obvious that the first or more complete change is one in which the gases evolved would be entirely without odour, but the N, being in the free state, is lost: in the second or less complete anaerobic change, the gas will have an ammoniacal odour, and would be offensive if allowed to escape into the air. The effluent also will contain combined N in the form of NH_3 and compound ammonias, and make it absolutely necessary to insure that adequate nitrification should follow. In this case the final effluent theoretically contains all the original organic N in the form of nitrate, which is available for plant nutrition.

The "bye-product" of these re-actions is a varying but small quantity of dark pulverulent matter resembling the humus or peaty substances of soil. It is of somewhat indefinite constitution, containing nitrogen but is innocuous from its very stability. It partially subsides and gradually disappears, while the suspended portion may cause turbidity and colour in the liquid, which are removed in the subsequent oxidation by porous aerobic media.

As compared to the voluminous "sludge" of chemical or mechanical treatment, the anaerobic liquefaction leaves only a small quantity of this earthy matter which requires no special provision.

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* *Ann. Chim. Phys.*, 1898, vii, 45.

The amido-acids formed in liquefaction break up into fatty or aromatic acids and ammonia. Since many of them are very stable bodies, the decomposition is slow. Following the general rule, being products of bacterial action, they hinder the activity of the bacteria themselves, furnishing an additional argument for the constant removal of the products by a continuous, as opposed to an intermittent system.

Among the amido-acids that have been found as products of albuminous putrefaction are :—

Name.	Constitution.	Formula.	Products.
Glycocine	Amido-acetic	$\mathrm{CH_2(NH_2)COOH}$	Ammonia and acetic acid.
Leucine	Amido-isocaproic	$\begin{cases}\mathrm{C_5H_{10}(NH_2)}\\ \mathrm{COOH}\end{cases}$	Ammonia and isocaproic acid.
Tyrosine	β-oxyphenol-amido-propionic	$\begin{cases}\mathrm{CH_2C_6H_4(OH)}\\ \mathrm{CH_2(NH_2)COOH}\end{cases}$	
Aspartic	Amido-succinic	$\begin{cases}\mathrm{CH_2\ COOH}\\ \mathrm{CH(NH_2)COOH}\end{cases}$	Ammonia and malic acid, then succinic.
Asparagin	Amido-succinamic	$\begin{cases}\mathrm{CH_2CO(NH_2)}\\ \mathrm{CH(NH_2)\ COOH}\end{cases}$	Ammonia and malic acid, then succinic.
Glutamic		$\begin{cases}\mathrm{C_3H_5(NH_2)}\\ \mathrm{(COOH)_2}\end{cases}$	Ammonia and probably succinic acid.

Tyrosine has been said to be strongly antiseptic, but its quantity in fæces is small, and it is largely diluted in the sewage. It breaks up into indol, skatol, phenol, and acids related to benzoic. *Spirillum rugula* and the *B. coprogenes* group develop a strong fæcal odour, probably owing to this reaction. In the Exeter and Ashtead hydrolysed effluents I only found leucine unchanged ; acetic, butyric, and caproic acids were, however, isolated, and traces of succinic as well as indol and skatol.

The development of these more or less antiseptic substances in the intestines probably accounts for the excreta not being further liquefied in the body, although large numbers of the necessary organisms are present : on emerging, however, and undergoing dilution, the bacteria at once become active.

The basic amines are of two classes :

(1) Non-volatile crystalline compounds known as *ptomaines* and leucomaines : they are poisonous, but that they are destroyed

in the subsequent aerobic treatment is shown by the fact that the final effluents are not poisonous to fish.

(2) Volatile bases or substituted ammonias, usually of strong odours and alkaline. These, in the ordinary method of analysis by distillation are partly put down as "free ammonia," which includes not only the ammonia existing as carbonate, but also that combined with the organic acids as salts, as well as such compound ammonias as react with Nessler test. Many years ago Young pointed out that in the usual mode of distillation a good deal of volatile nitrogenous matter escaped which was not recorded by Nessler test. I have often also indicated that the conventional procedure in the Wanklyn determination gives an "albuminoid ammonia" which is far short of the fixed organic nitrogenous matter, probably accounting for such low figures as 0·34 (with 13·8 of chlorine) and 0·24 (with 10·3 of chlorine) for raw sewages in the recent Manchester and other reports. The Kjeldahl process, on the other hand, gives the whole of the ammoniacal and organic nitrogen.

In a septic tank effluent I lately found, by fractionation of the hydrochlorides in parts per 100,000 :—

Actual ammonia	3·48
Monomethylamine, CH_3NH_2	0·844
Trimethylamine	traces

the original having given 4·6 parts of "free ammonia," and (by Kjeldahl) 1·98 parts of fixed organic nitrogen, with a chlorine content of 6·2.

Trimethylamine has a fishy smell, which is very marked in some sewages. *B. ureæ*, *B. prodigiosus*, and *B. fluorescens putridus* develop this compound during putrefaction ; Amylamine and others are also found. The chief importance of the group lies in—

1. Their volatility and odours ;
2. Their removing carbon as well as nitrogen ;
3. The toxic nature of some, by which they hinder the subsequent nitrification. Therefore—

(*a*) The preliminary liquefaction should be conducted in a closed chamber ;

(*b*) The amines must be removed by a nitrous or other oxidation in the second part of the process, before reaching the nitric organisms.

IV. *The formation of organic acids and fermentation of their salts.* In the breaking up of complex organic molecules a number of organic acids are set free, and combine with any bases present, their salts being afterwards further broken down by such fermentations as are given in the annexed table, adapted from Dr. E. Herfeldt's summary of the varieties of septic fermentations.*

TABLE OF FERMENTATION OF ORGANIC ACIDS.

(For simplicity, the sodium salts are taken, though the lime salts are rather more fermentable.)

Salt fermented.	Cause of fermentation.	Products.
Formate ..	"Bacteria from sewage slime."	Acid sodium carbonate, $NaHCO_3$, carbonic acid and hydrogen.
Acetate ...	Ditto.	Acid sodium carbonate, $NaHCO_3$ carbonic acid and methane, CH_4.
Lactate ... Undergoes four different fermentations.	"Thin bacillus" (Fitz). "Other species of bacteria; short aerobic butyric bacteria" (Fitz).	1. Propionic acid, and as bye-products, acetic and succinic acids, and alcohol. 2. Propionic and valeric acid. 3. Butyric and propionic acid. 4. Butyric acid and hydrogen.
Malate ... Different fermentations.	Bacteria, not described; "Thin bacilli." B., lactis aerogenes (O. Emmerling).	1. Chief product—propionic acid; bye-product—acetic acid. 2. Chief product—succinic acid; bye-product—acetic acid. 3. Butyric acid and hydrogen. 4. Lactic acid and CO_2.
Tartrate ...	Different species of bacteria.	1. Chief product—propionic acid; bye-product—acetic acid. 2. Butyric acid. 3. Chief product — an acetate; bye-products—alcohol, butyric and succinic acids.
Citrate... ..	"Small, thin bacilli."	Acetic acid in large quantities, with small quantities of alcohol and succinic acid.
Glycerate ...	Micrococci; medium-sized bacilli.	1. An acetate, with small quantities of succinic acid and alcohol. 2. Formic acid, with some methyl alcohol and acetic acid.

[Under active microbic fermentation all eventually pass into CO_2 and H or CH_4. The CO_2 is partly free, and partly as bicarbonate of the base. Acetic acid is generally the penultimate product, therefore the common production of methane. Any amides of the acids are hydrolysed, with liberation of ammonia].

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* *Centr. f. Bakt.*, Jan. and Feb., 1895; *Jour. Soc. Chem. Industry*, May, 1895.

Hoyer* has lately shown that acetic acid bacteria live in absence of air, and under this condition reduce indigotin, methylene blue, and litmus, with liberation of CO_2. As sources of nitrogen, they can utilize peptone, asparagin, nitrites, and ammonium salts, whilst acetates, lactates and sugar can serve as sources of carbon. This shows that aerobic and anaerobic species are by no means rigidly separated ; very few are obligatory in either sense.

There are also ferments existing in fungi and most vegetables, called by Bertrand "Oxydases," which are capable of acting on phenol and the aromatic compounds in the second stage.

The rapid oxidation of organic acids in presence of traces of ferrous salts, which always exist in sewage, seems to take place without the agency of bacteria, and is being investigated by Fenton and Jones,† and others.

V. *Solution of Cellulose and Fibrous Matters.*—Mitscherlich in 1850 proved that cellulose was dissolved by fermentation, and Van Tieghem‡ in 1870 describes the most active organism as *B. amylobacter*, anaerobic, and derived principally from the intestines of animals. It is always found in putrefying infusions, and hydrolyses sugars and starches as well as cellulose, giving butyric acid and hydrogen, whence its later name of *B. butyricus.* Tappeiner§ fermented cotton-wool and paper pulp in a weak nitrogenous solution, and obtained CO_2 and methane in neutral, and CO_2 and H in alkaline solution. Hoppe-Seyler‖ in 1886 found only traces of soluble residues, and concluded that at first a soluble carbohydrate was formed by the action of water, and that this was then split up into carbonic acid and methane—

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6$$
$$C_6H_{12}O_6 = 3\ CO_{20} + 3\ CH_4$$

If more water took part, less CH_4 and more H would be obtained.

Horace Brown, about 1894, investigated a cellulose-dissolving enzyme in the digestive tract of herbivora. He found that the enzyme was secreted by the plants themselves, and came into activity under favourable conditions. "Rot-steep," or retting of flax, and skeletonizing of leaves, are processes of similar character.

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* *Chem. Centralblatt*, 1899, i , 854.

† *Chem. Soc. Trans.*, Jan., 1900, p. 69.

‡ *Zeit. Phys. Chem.*, vi. 287, and *De Bary's Lectures.*

§ *Zeits. f. Biol.*, xxiv., 105.

‖ *Zeits. Biol.*, x., 401.

Von Senus, in 1890, proved the fermentation of fibre to be anaerobic, that it was occasioned by a symbiosis, or concurrent action of *B. amylobacter* with other organisms, and that gaseous products of the above character finally remained. He isolated an enzyme which dissolves fibre, and also a group of the resolving bacteria from mud, stomach-contents, and decaying vegetable matter.

Brown and Morris* have also isolated from fungi a similar or identical ferment called "cytase," quickly dissolving celluloses.† It is well known how rapidly *Merulius lachrymans*, or "dry rot," softens the fibre of hard wood.

In laboratory experiments with different kinds of cellulose, paper, cotton-wool, etc., in water inoculated with sewage organisms, I have observed gradual liquefaction with the production of inflammable gases.

The changes occurring in silos and in manure heaps, may be noticed as examples of the anaerobic breaking down of cellulose and fibrous matters.

Vasculose (Fremy), constituting the harder parts of plants, is also slowly disintegrated by organisms.

The smaller remains of vegetable matter which pass down sinks, occasion considerable nuisance when an attempt is made to remove them by screens, or on the top of a coarse filter. They act objectionably in three ways:—

1. They set up acid fermentation and corrode iron.
2. A large proportion of domestic vegetable débris (cabbage etc.) contains sulphur compounds, and evolves, on decomposition, very offensive odours.
3. They form a pulp which blocks the strainers.

Under anaerobic conditions in a closed space they rapidly rot away and disappear, their pectose first dissolving, and then their cellulose, while the ammonia takes up the acids.

VI. *Fermentation of other Carbohydrates.* Starch, different sugars, and gummy substances undoubtedly enter into sewage. But their hydrolysis is so rapid, that very little trace of them is found after a short period. The ferments in human fæces allied to diastase and invertase were investigated in 1887–88 by O. Loew[*] Pavy,[†] and R. von Jaksch.[‡] These fermentations, such as the alcoholic, which are usually occasioned by higher fungi like yeasts and moulds, do not present themselves distinctly, although the *B. coli communis* is capable of fermenting sugars and producing lactic acid, alcohol, and a volatile acid. The changes are either lactic from *B. acidi lactici*, or butyric from *Clostridium butyricum*, or *Bacillus butyricus* (both anaerobic), and give, besides the respective acids, carbonic acid, hydrogen, and water.

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* *Trans. Chem. Soc.*, 1890, p. 497.

† Also see J. G. Green, *Phil. Trans.*, 1887, clxxviii., 57; Marshall Ward, *Annals of Botany*, 1888, ii., 319; Reinitzer, *Zeit. Phys. Chem.*, 1897, xxiii., 175; Biedermann and Moritz, *Pflüger's Archiv.*, 1898, lxiii., 219.

VII. *Decomposition of Fats.*—Soap-suds and greasy matters occasion considerable trouble in the mechanical treatment of sewage. At Bradford the refuse of wool-scouring has been the chief difficulty for years. The sewage has been precipitated chemically by ferric sulphate, but in addition to the large quantity of chemicals required, and the unsatisfactory character of the effluent, the very large amount of grease in the sludge obstructs the filter presses, and renders it impossible to reduce the water below 95 or even 98 per cent., which not only increases its weight and bulk, but also the difficulty of drying.

In a bacterial tank the grease is first emulsified by the ammonia. There are several bacteria that attack fats in presence of nitrogenous substances,[§] breaking them up into the simpler acids of the fatty series, like acetic and butyric, which in their turn are finally resolved as on p. 84. Many common moulds also act on fats, notably the ordinary green mould, *Penicillium glaucum*, which Hanriot found to contain *lipase*, besides emulsin and other ferments. Moulds are not commonly present in the anaerobic stage, but occur in the second, or limited aeration. Ritthausen and Baumann found that a great destruction of fat occurred by the action of moulds and bacteria in a substance containing proteids as well; the substance they experimented on was rape-cake.[||] The glycerine also ferments.

VIII. *The Sulphur Fermentation.*—Dr. Sims Woodhead found *Bacterium sulphureum* in the Exeter tank. It liquefies gelatine, casein, and other albuminoids, and produces sulphuretted hydrogen. Several observers did not, however, find H_2S in the tank gases. I have found that a mercaptan (methyl hydrosulphide) and other ethereal compounds are undoubtedly present in small quantities. They are very soluble, and easily oxidized.

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[*] *Pflüger's Archiv*, xxvii., 203.

[†] *Maly's Jahresb.*, xiv., 294.

[‡] *Zeit. phys. Chem.*, xii. 116.

[§] *Sommaruga, Zeits. Hyg.*, xvii. 441.

[||] *Landw. Versuchs. Stat.*, xlvii. 386, 1896.

Most of the sulphur, however, enters into combination with the iron present in the sewage, forming insoluble ferrous sulphide and giving a black colour to the suspended matter. When the black matter is treated with acids, sulphuretted hydrogen is evolved and the substance becomes brownish, just as when strong acid effluents from factories are discharged into ditches or on to the black mud banks of neglected rivers, a liberation of sulphuretted hydrogen occurs. In the tank, however, the ferrous sulphide is protected by the ammonia ; on reaching the oxidation stage it is converted into a basic ferric sulphate, forming an ochreous coating on the materials, which considerably assists in the transfer of oxygen.

A proportion of the bacteria escape from the septic tank or other anaerobic chamber ; but a large number remain entangled in a *zooglœa* mass either at the top or bottom of an unobstructed tank, or as a layer on the surface of the flints or other filling material.

With the exception of not requiring extraneous heat, the first stage of anaerobic resolution of organic substances is analogous to the decomposition of coal in gas retorts, the chief products, free hydrogen and methane, CH_4, being identical : in fact, the latter has been called " marsh gas " from its being produced in stagnant pools where hydrolytic changes occur beneath the surface. As disengaged from closed tanks the gas is found to burn with a blue flame, like that of an ordinary atmospheric burner, giving great heat, which can either be utilized under boilers, or by means of incandescent mantles be applied to the lighting of the works. At Exeter, a gas lamp of the usual street pattern is fed from the gases of the septic tank. The residual gaseous energy that is available in this way can be approximately calculated from the consideration that the organic matter removed from the sewage and converted into gas in the tank is, for the most part, not oxidized or burnt therein. The oxygen-consumed figure of the raw sewage, with its suspended matter, less the oxygen-consumed figure of the tank effluent, gives a measure of the combustibility of the gases produced. For example :—

PARTS PER 100,000.

	Oxygen-consumed Figures.		
	Raw Sewage.	Tank Effluent.	Difference.
Exeter	6·56	4·32	2·24
Caterham	14·97	9·25	5·72
Yeovil	7·43	6·11	1·32

It is easy to understand, bearing in mind ordinary burning, how, in oxidation changes, energy is obtained for the continuance of the reaction. In hydrolytic changes, the source of energy is not so clear, but it will be seen that in these decompositions, there is a distinct evolution of heat, small in amount, and almost imperceptible in the bulk of water, but sufficient to continue the reaction, which is commonly known, therefore, as *exothermic*, or, containing within itself the conditions of its own propagation. Thus in the case of urea—

$$\mathrm{CO(NH_2)_2} + \mathrm{H_2O} + \mathrm{Aq} = \mathrm{CO_2} + \mathrm{2NH_3Aq}$$

$$\text{Heats of formation} \quad \underbrace{+\ 77{\cdot}5 \qquad +68{\cdot}4}_{145{\cdot}9} \quad \underbrace{+97{\cdot}6 \qquad 2\times(+20{\cdot}4)}_{138{\cdot}4}$$

but the $2\mathrm{NH_3}$ and $\mathrm{CO_2}$ neutralize one another, resulting in a further evolution of about 20 units.

Hence

145·9 must be absorbed while 158·4 must be evolved, giving a balance of $\underline{12{\cdot}4}$ units evolved.

[The units are kilogram-centigrade and the substances are taken in gramme molecules.]

Cellulose.

$$\mathrm{C_6H_{10}O_5} + \mathrm{H_2O} = 3\ \mathrm{CO_2} + 3\ \mathrm{CH_4}$$

$$\text{Heat of formation} \quad \underbrace{246 \qquad\qquad 68} \qquad \underbrace{291 \qquad\quad 49{\cdot}5}$$

Heat absorbed 314 Heat evolved 340·5

Evolution of heat $\underline{26{\cdot}5}$ units.

[I have calculated the heat of formation of cellulose thus :—

Complete combustion of 6C and 10H to $\mathrm{CO_2}$ and water :

$$6\mathrm{C} + 5\mathrm{H_2} + \mathrm{O}\ \text{in excess} = 6\mathrm{CO_2} + 5\mathrm{H_2O}$$

$$\underbrace{6\times 97 \qquad 5\times 68{\cdot}4}_{924\ \text{units}}$$

Combustion of cellulose $\mathrm{C_6H_{10}O_5}$ gives 678 units (Stohmann).

$$924 - 678 = 246.]$$

Albumen.

Berthelot and André* state that one gramme of albumen dried at 100° C. gives 5691 calories (gram-centigrade units).

Hence $C_8H_{13}N_2O_3 = 185$ of albumen give $185 \times 5691 = 1{,}052{,}835 = 1{,}053$ kilogram units.

We must first calculate from this the heat of formation of albumen.

$$\begin{array}{llllll} (8C + 13H + 2N + 3O) \text{ burnt} = & 8CO_2 & + & 6H_2O & + N_2 + H \\ & 8 \times 97 & & 6 \times 68 & \\ & 776 & + & 408 & = 1{,}184 \end{array}$$

Hence heat of formation $= 1{,}184 - 1{,}053 = 131$ units.†

Now assuming a complete hydrolytic change :—

$$\begin{array}{lllll} & 4C_8H_{13}N_2O_3 + 14H_2O & = & 4N_2 + 19CH_4 + 13CO_2 + 4H \\ \text{Thermally} & 4 \times 131 \quad 14 \times 68 & & 19 \times 16{\cdot}5 \quad 13 \times 97 \\ & 524 + 952 & & 314{\cdot}5 + 1{,}261 \\ & 1{,}476 \text{ absorbed} & & 1{,}575{\cdot}5 \text{ evolved} \end{array}$$

giving a balance of $1{,}576 - 1{,}476 = 100$ units evolved.

It is curious that the percentage of the heat evolved in the products is in each case nearly the same :—

	Heat in products.	Heat evolved.	Per cent.
Urea	158·4	12·4	8
Cellulose	340	26·5	8
Albumen	1,575	100	7

These enzyme reactions follow the ordinary chemical law of going in the direction of an evolution of heat. They occur at atmospheric temperature, and it has been pointed out by Van t'Hoff that the lower the temperature the more nearly will Berthelot's law of maximum work be obeyed.

THE SECOND STAGE, OR SEMI-AEROBIC BREAKING DOWN OF THE INTERMEDIATE DISSOLVED BODIES,

is not generally distinguished sufficiently from the first, nor allowed adequate time to develop. It occurs in the upper layers of bacterial filters, as requiring little oxygen, and results generally in the production of *nitrites*, the conditions being favorable to the growth of *B. Nitrosomonas*. In this stage the amido-compounds, fatty acids, and dissolved residues of hydrolysis undergo a further resolution.

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* *Chem. Soc. Abstracts*, 1890, p. 937.

† I have left out one hydrogen atom in this calculation, because in the enzyme reaction one hydrogen per molecule of albumen is set free.

Nitrosification, or the production of nitrites, and secondarily of nitrogen and its lower oxides, by partial oxidation, should normally occur in the second stage of bacterial purification. Wherever we find a final filter acting badly, either from deficient aeration, or other cause, the fault is at once indicated by the appearance of a high proportion of nitrites, as *nitrosification* is not nearly so delicate a process or so difficult to initiate or control as *nitrification*, or the production of nitrates, which it would naturally precede. For example:—P. F. Richter isolated a coccus of medium size, which in 20 minutes produced a very intense nitrite re-action *in fresh urine*, and in addition reduced nitrate to nitrite, a retrograde change which I have already remarked as common to many bacteria, and characteristic of crude attempts to introduce nitrification before the sewage is properly hydrolysed and prepared. Nitrosification proceeds most rapidly in the presence of diffused light and of a moderate amount of air. In many processes the purification goes no farther, when nitrification is not subsequently active.

The nitrosification change is, however, very valuable in the second stage, as getting rid of the transition products, ammonia, amido-acids, and the amides by double decomposition into water, or hydroxy-compounds (which are afterwards broken up by fermentation) and nitrogen gas. As simple instances we have :—

$$NH_3 + HNO_2 = 2H_2O + N_2$$

$$\underset{\text{Amido-acetic acid.}}{(NH_2)\,CH_2\,COOH} + HNO_2 = \underset{\text{Glycolic acid.}}{(OH)\,CH_2\,COOH} + H_2O + N_2$$

$$\underset{\text{Ethylamine.}}{(NH_2)\,C_2H_5} + HNO_2 = \underset{\text{Alcohol.}}{C_2H_5OH} + H_2O + N_2$$

In the process nitrogen and carbonic acid are evolved, but scarcely any hydrogen, nor methane.

This change is, therefore, accompanied by a great loss of nitrogen, and a removal of odour. It takes place in the resting full period of filters, and causes a greater loss of nitrogen than of carbon.

Grimbert* has shown that the *Bacillus coli communis* and the

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**Annales de l'Institut Pasteur*, January, 1899.

Bacillus typhosus do not disengage gas in 1 per cent. solution of peptone plus 1 per cent. potassium nitrate, but that gas is produced when the peptone is replaced by meat extract which contains simpler amido-compounds. When these organisms disengage gases in a medium containing nitrates, the volume of nitrogen evolved is always about double the amount which the nitrate destroyed could possibly produce, proving that the nitrogen does not come exclusively from the nitrates, but results from the secondary reaction between the nitrous acid produced by denitrification and amido-substances. Nitrites do not hinder the action of the bacilli, as the latter develop very well in a medium containing 1 per cent. of nitrites, and disengage an equal or even larger quantity of nitrogen than in the same medium containing 1 per cent. of nitrates. He believes that this is the explanation of the loss of nitrogen in the soil.

Another mode in which nitrous compounds act valuably is that by their instability they serve as carriers of oxygen from the air to the organic matter, in a way similar to their well-known action in vitriol chambers. Bearing in mind the large production of carbonic acid in sewage purification, and the fact that nitrous is a weak acid, an observation of Müntz is instructive.* He found that the calcium nitrite in sterilized soil, when CO_2 was passed over it, gave off nitrous acid rapidly, but on exposure to air, or on passing CO_2 largely diluted with air, it was quickly oxidized to nitrate. I shall have again to allude to this change later.

As an example of the production of nitrites, three Exeter filtrates, which on June 18th contained only "heavy traces," were analyzed on June 30th, twelve days later.

PARTS PER 100,000.

Number.	Original N as Nitrate.	After 12 days.	Original N as Nitrite.	After 12 days.
VI.	1·01	1·152	Very heavy trace	0·48
VII.	0·590	0·624	Heavy trace	0·666
VIII.	0·696	0·768	Heavy trace	0·55

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* *Comptes rendus*, 1891, cxii, 1142.

A later sample will further illustrate the instability :—

—	Nitrogen as Nitrates.	Nitrogen as Nitrites.
Nov. 10th, 1897	1.49	·030
Nov. 18th ,, ...	1.51	·74
Dec. 2nd ,, ...	2·58	Trace.

In an effluent from the septic tank at Exeter, on November 10th, the nitrate was 0·030, the nitrite none ; on December 2nd, the nitrate was 0·060, the nitrite excessive ; in this case the nitrite had been formed from ammonia, and not by reduction of nitrate. An instance of the transfer of oxygen by means of the oxidized nitrogen compounds, resulting in a reduction of the organic carbon, without a corresponding decrease in the amount of total nitrogen, was given by my analyses of the Caterham effluents in 1899, when kept for a short time in stoppered bottles partially full.

Samples.	No. 1.		No. 2.		No 3.		No. 4.		No. 5.	
	Jan. 26	Feb. 1	Jan. 27	Feb. 1	Jan. 28	Feb. 1	Jan. 30	Feb. 1	Jan. 31	Feb. 1
Ammoniacal N.	12·15	11·9	12·56	12·1	12.35	11·54	21.4	20·6	23·8	
Organic N ...	·618	·412	·823	1·03	·618	·41	1·23	1·44	0·82	
Nitrous N ...	·148	·074	1·924	1·702	1·184	1·40	0·407	0·41	0·59	0·666
Nitric N	7·68	9·0	4·14	4·36	5·60	6·46	10·3	10·64	6·46	5·52
Total Nitrogen	20·596	21·386	19·447	19·192	19.752	19·81	33·337	33·09	31·67	
Oxidized Nitrogen	7·828	9·74	6·064	6·062	6·784	7·86	10·707	11·05	7·05	
Percentage of Nitrification	38	45·5	31	32	34·5	39·6	32·	33·4	22·3	19·5
Oxygen consumed... ...	3·32	2·24	6·27	4·43	4·19	3·47	4·85	2·78	4·52	
Chlorine... ...	18·5	—	19·75	—	21·5	—	22·15	—	24·35	
Percentage of reduction in the Oxygen consumed ...	—	32·5	—	30	—	17	—	43	—	

The chief change seems to have been a transfer of the oxygen of the air by means of the nitrous acid to the carbonaceous matter. The nitrifying and nitrosifying changes appear to have gone on continuously, the nitric being reduced to nitrous by the carbonaceous matter, which was thereby oxidized, and the nitrous again absorbing oxygen and re-forming nitric. In Nos. 1 and 3 the nitrogenous organic matter has taken part; but the change as a rule is not a Gayon and Dupetit one (see p. 98), as no loss of total N as gas has occurred. It is simply an oxidation of carbon.

THE THIRD STAGE, THAT OF COMPLETE AERATION, comprises the final oxidation of the nitrogenous and carbonaceous residues, and includes the formation of nitrates or *nitrification.*

The amount of oxygen required for the processes of nitrification and nitrosification is shown in the following Table :—

One Gramme of nitrogen requires :—

For production of	Grammes of oxygen.	Litres of oxygen.	Litres of air.	Litres of oxygen-saturated water at 7cc. per litre
N_2O_5	2·85	2·0	10·0	286
N_2O_3	1·7	1·2	6·0	170
N_2O_2	1·13	0·8	4·0	114
N_2O	0·57	0·4	2·0	57

So that to nitrify in an effluent, five parts of nitrogen per 100,000 (1 gramme in 20 litres) will demand about half its volume of air, or about fifteen volumes of fully aerated water. This explains the comparative failure and frequent collapse of filter beds in large masses, especially if the fluid is a raw sewage or a merely screened or precipitated effluent without preliminary hydrolytic change, as with every 100,000 gallons of sewage, about 50,000 gallons of air must be continuously supplied.

Contrivances like fountains, cascades, and weirs can only raise the dissolved oxygen to the saturation point of about 7cc. per litre, or 700 gallons per 100,000; although useful, if simple, like the aerator at Exeter,* they are quite inadequate.

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* In Nov., 1896, I found that while the Septic Tank Effluent contained no oxygen, after passing over this aerator it had dissolved 0·56 cc. per litre.

At Manchester, in 1897, Mr. Fowler investigated the conditions under which the (chemically precipitated) effluent would become purified by exposure to air out of contact with any filtering medium. He concluded that:—

"Exposure to air is only effective . . . . when exposed in shallow layers, and for a considerable period of time . . . . It is not probable that aeration sufficient to at all adequately oxidize an effluent could be produced by any system of cascades which could be applied in a practical form."

The following table summarizes some of his experiments:—

Air passing over surface			Air drawn through liquid.		
Hours exposed.	O consumed.	Per cent. reduction.	Hours exposed.	O consumed.	Per cent. reduction.
0	2·52	—	0	2·00	—
21	2·58	—	4	2·08	—
27	2·57	—	6	2·00	—
72	1·44	43	23	1·62	19
95	1·26	50	27	1·50	25
100	1·21	52	47	1·31	35
117	1·16	54	51	1·20	40
141	0·80	68	71	0·90	55
			95	0·51	74

Complete analyses:—

	O consumed in four hours.	Free and saline ammonia.	Albuminoid ammonia.
August 9th ...	3·38	1·25	0·18
" 11th ...	1·46	1·55	0·10

On these results it would seem that:—

1. The change conforms at first to what I have called Stage II., the partially aerobic in which the *nitrites* formed increase the "oxygen consumed."

2. A steady reduction of the carbonaceous matter then occurs from the double decompositions we have indicated.

3. The inception of nitrification in stage III. probably follows, though as the nitrates are not given, the point cannot be ascertained.

4. That not much acceleration is produced by forcing the air through the liquid, as against simply passing over the surface of shallow layers.

5. That the improvement by aeration alone for four to six days is inferior to that effected by bacterial filters in eight hours.

6. That determinations limited to the "oxygen consumed" are insufficient for revealing the character or amount of the purification.

The third stage, in fact, includes much more than a simple process of oxidation, although it demands a supply of oxygen in excess.

Nitrification proper, or the production of nitrates, is due to one or more organisms capable of growing in culture solutions which are practically free from organic carbon. But, under natural circumstances, they act in succession to nitrous organisms, and in the presence of organic material, which they do not, however, by themselves decompose.* Some of the difficulties of the subject have been cleared up by Adeney's researches, who, by cultivation in known solutions, has eliminated disturbing factors. His conclusions are:

1. In inorganic solutions, containing ammonia, nitrous organisms thrive, but nitric organisms gradually lose their vitality.
2. Nitrous organisms cannot oxidize nitrites to nitrates in inorganic solutions.
3. Nitric organisms thrive in inorganic solutions containing nitrites.
4. The presence of peaty or humous matter appears to preserve the vitality of nitric organisms during the fermentation of ammonia,† and establishes conditions whereby it is possible for the nitric organisms to thrive simultaneously in the same solution as the nitrous organisms.

In corroboration of this opinion Alfred Beddies‡ has lately cultivated nitrifying bacteria from manure heaps in a nutritive solution containing one per cent. of a strong solution of humus and 0·25 per cent. of sodium silicate, and finds that in this way the organisms were much more stable than those obtained by Winogradsky in the absence of organic matter (p. 60). Four stable varieties of nitric and three of nitrous bacteria were isolated, the stronger forms being singularly unaffected by changes of temperature, and growing freely together without interference. He obtained evidence that in presence of an abundance of nitrifying organisms, denitrification is hindered, and there is no loss of free nitrogen ; when, however denitrifying organisms predominate, the nitrifying bacteria are injured, especially if aeration is limited. This is in accordance with what we have observed in connection with some bacterial filters.

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* *Winogradsky, Centr. Bakt. Par.*, 1896, 2, ii. 415 and 449. See also *Centr. Bakt.*, 1899, 652; *Mitt. Landw. Breslau.*, 1, 75; 2, 197; *Compt. Rend.*, 1899, 566.

† As to the production of peaty matter by B. mesentericus see Julius Stocklasa (*Bied. Centr.*, 1899, xxviii, 588).

‡ *Chem. Zeit.*, 1899, xxiii, 645.

In an effluent which is properly prepared and well aerated, nitrification can often be encouraged by seeding with a small quantity of a fertile garden soil.

The conditions of nitrification have been often stated but may be recapitulated.

(*a*) In every case the formation of ammonia by some other organisms precedes the appearance of nitrous or nitric acid (p. 76).

(*b*) Some fixed base must be present to combine with the acid formed. Therefore, in a sewage farm, if the soil is devoid of lime it must be added. Ordinary sewage contains fixed alkali derived from washing soda, and any acid discharges are generally neutralized by this and by the free ammonia. E. Chuard* found that nitrification may occur in an acid medium, but that it was very slow. Hence in strong manufacturing effluents a treatment with lime may be necessary before nitrification will take place.

(*c*) The solution must not be too strong, nor too alkaline. Warington found that a 12 per cent. solution of urine was the highest strength nitrifiable, and that the maximum alkalinity corresponded to 36·8 parts per 100,000 of N as ammonium carbonate, equal to 44·6 parts of ammonia. These are strengths which only under special circumstances would be approached in sewage. In the runnings from urinals, stables, etc., dilution would be necessary.

(*d*) Darkness and free admission of air.

In natural soil, Warington proved that nitrification rapidly diminishes after 3 feet, and that there is no nitrification below 6 feet. Thudichum states that the maximum limit of depth for the best results from filter beds is 3 feet to 3½ feet. "Beds have worked well at 4 feet to 5 feet, but the alteration of a bed from 3½ feet to 5 feet was accompanied by some reduction in the quality of the effluent."

Here I may incidentally draw attention to a curious fact. In nearly all published analyses, the chloride in the effluent is slightly lower than that in the corresponding sewage. Muntz pointed out that in nitrification, bromides and iodides were oxidized to bromates and iodates. Chili saltpetre, nitrate of soda, which has been produced by natural nitrification, often contains a small percentage of perchlorates. Dr. Tidy, some 20 years ago, found a loss of chloride in waters running over aerating wooden shelves, and suggested that it might be due to the formation of chlorates. I have not yet been able to find them in effluents.

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* *Comptes Rendus*, cxiv., 181.

At this stage an abundance of carbonic acid is formed by fermentations due to other classes of bacteria. I have found in several bacterial filters intended to be aerating and final, such a large quantity of carbonic acid as must seriously retard their nitrifying action; the result being a deficiency of nitrates in the effluent. Especially is this the case where the final beds are made by a process often recommended for economy,—that of simply digging out the clay to form a pit about three feet deep, and filling it up with the same clay after burning.

Denitrification. This process has been largely investigated, from the fact that in agriculture it is a retrograde change, involving great loss in the value of manure. But in the treatment of sewage it is capable of rapidly effecting a great amount of purification. As early as 1886 Gayon and Dupetit* investigated the change of nitrates with evolution of nitrogen oxides and nitrogen gas by the agency of bacteria. Two organisms were isolated from sewage, which, in the presence of organic matter, decomposed nitrates with production of nitrogen and nitrous oxide. These authors state, that in a nitrated medium they were anaerobic, taking oxygen from the nitrate, and that in certain solutions as much as 9 grammes per litre of nitrate could be decomposed. By exact analysis of the evolved gases, and of the fermented liquids, the authors show that the whole of the nitrogen of the nitrate is evolved as gas, and that its oxygen combines with the carbon of the organic matter to form CO_2, a portion of which may be evolved as gas, while the remainder combines with the base to form an acid carbonate. Organic matter is essential to the reaction. "1 grm. KNO_3 requires 0·148 C or 0·273 grm. of albuminoid matter for its complete decomposition." The $N + N_2O + CO_2$ account for all the nitrogen and carbon, and for the available oxygen of the nitrate. The denitrifying bacteria will not develop in liquid deprived of nitrate and out of contact with air, nor will they attack organic matter under these circumstances. The authors further proved denitrification to be a fermentation which consists in the direct burning up of organic carbon at the expense of the oxygen of a nitrate.

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* Station Agronomique de Bordeaux, 1886.

Ampolla and Ulpiani, in 1898,[*] describe two bacteria which act similarly, giving, as they state, complete decomposition of the organic matter and nitrate to CO_2 and N, without intermediate production of nitrite. Sugars, fatty and amido-acids were equally broken up, thus :—

$$5\ C_6H_{12}O_6 + 24\ NaNO_3 = 24\ NaHCO_3 + 6\ CO_2 + 18\ H_2O + 12\ N_2$$

Thus 5 of oxygen are utilized instead of 4, as in the production of N_2O. This is the explanation of what I have said about "available oxygen," and the reason why an effluent that has been properly fermented and heavily nitrated is capable of rapid self-purification, and also of improving the condition of a river into which it may be discharged.

Adeney, in fact, introduced a process in which he added nitrate of soda at the third stage to accomplish by denitrification the final removal of any organic matter present.

As we have seen that the effluent can be naturally nitrified by properly constructed filters, the expense of an artificial supply is not required.

Hugounenq and Doyon[†] observed that *B. coli communis* under favourable circumstances decomposes nitrates, setting free nitrogen and utilizing the oxygen. Warington proved at Rothamsted that the loss of nitrogen from manure increased in proportion to the fermentable organic matter.[‡]

Burri and Stutzer observed that their *B. denitrificans II.* liberated 90 per cent. of the nitric nitrogen from Giltay's solution as free N. Giltay himself obtained 80 per cent., Stutzer as much as 98·9 to 99·6 ; a certain amount of the nitric N being converted into organic N in the protoplasm etc. A considerable amount of CO_2, and some H, was produced. The organisms could thrive without air, but seemed to require air when they first began to develop.

The disappearance of nitrates from sewage filtrates is illustrated by the following experiments :—

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[*] *Gaz. Chim. Ital.*, xxviii. (1) 410 ; *Jour. Soc. Chem. Ind.*, p. 1,160, Dec. 1898.

[†] *Ann. Chim. Phys.*, 1898, vii., 45.

[‡] *J. Roy. Agr. Soc. Eng.*, 1897, III., viii., 577.

Nine volumes of a hydrolysed effluent from a closed tank, free from either nitrite or nitrate, were mixed with one volume of a coke-breeze filtrate containing 4·34 parts per 100,000 of N as nitrate, and no nitrite, and the mixture kept *out of contact with air* for five days at 15° C. By this time the whole of the nitric nitrogen, amounting to 0·434 parts in the mixture, had disappeared, *without the formation of either nitrite or free nitrogen.* The same liquid afterwards in a vessel partially full and exposed to light yielded nitrites in abundance. In other experiments I found that the loss of organic nitrogen was not accounted for by the production of either nitric acid, ammonia, or nitrogen gas. Referring to the table (p. 94) it will be seen that nitrous and nitric oxides, N_2O and N_2O_2, remain as reduction products of the nitrates. Gayon and others have observed the production of *nitrous oxide*, which being soluble and neutral has no doubt often been overlooked. The rapid production of *nitrite* on exposure to air appears to indicate also the presence of *nitric* oxide. Percy Frankland also found that a common water organism, *B. aquatilis*, which does not form nitrites, yet in its growth caused a considerable disappearance of nitric nitrogen.[*]

Another form of denitrification is the reduction of *nitrate* to *nitrite.* This, as effected by bacteria was first shown in 1875, by Meusel,[†] who found that well-water containing nitrates on standing soon developed a reaction for nitrites—a change that was prevented by sterilization, or by certain antiseptics. The importance of the reaction was first insisted on by Wagner, of Darmstadt.

Percy Frankland[‡] gives the following list of 32 species that he examined :

I. Reducing nitrate to nitrite.—(Strongly)—*Bacillus ramosus*, *violaceus*, *vermicularis*, *liquidus*, *cereus*, *pestifer*, *plicatus*, *prodigiosus*, *chlorinus*, *citreus*.

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[*] *Chem. Soc. Trans.*, 1888, 391. [‡] *loc cit*, 372. [†] *Berichte*, viii., 1215.

See also on the same subject :
Hatton, *Chem. Soc. Trans.*, 1881, 266 et seq.
Gayon & Dupetit, *Berichte*, 1882, xv., 2736 } Anaerobic
,, ,, ,, 1883, xvi., 22 1 } organisms.
Déhérain & Maquenne ,, 1882, xv., 3081. B. butyricus.
R. Warington, *Chem. Soc. Trans.* } Organisms
Munro, ,, ,, ,, 1886, 632 } generally.
Heraeus, *Zeits. f. Hyg.*, 1886, 193. Pure cultivations.

(Slightly).—*B. nubilus*, *aurescens*, *fluorescens*, *aureus*, *profusus*; *Micrococcus carnicolor*, *rosaceus* (very slight).

II. Not reducing nitrate to nitrite.—*B. viscosus*, *arborescens*, *aurantiacus*, *subtilis*, *aquatilis*, *lævis*, *polymorphus*; *Sarcina aurantiaca*, *lutea*, *liquefaciens*; *Streptococcus liquefaciens*; *Micrococcus gigas*, *albus*, *candicans*, *chryseus*.

His chief conclusions were :—

1. The behaviour of the various organisms was the same, whether air was present or excluded.

2. None of the organisms examined could either produce ammonia from nitrate, nor oxidize ammonia to nitric acid.

3. The difference in reducing power gives a valuable distinction between otherwise very similar organisms.

Remarking on the common observation that the denitrifying organisms are mostly derived from straw, and are nourished specially by the gummy matters of straw and other vegetable fibre, R. Warington, in Rothamsted experiments,[*] states that his results in cultivation did not bear out the conclusion that (wheat) straw promoted denitrification. Probably this is explained by the observation of Matz and Wagner[†] that as " humification " proceeds, the power of destroying nitrates diminishes. W. Kruger and Schneidewind attribute the action of straw to the pentosans present, while sugars, glycerol, citrates, malates, etc., also promote the activity of denitrifying organisms, as well as excess of moisture (as in sewage), and a high temperature.[‡]

Th. Pfeiffer[§] shows that *denitrification* can only take place in presence of particles of straw, fæces or vegetable tissue which act as food to the denitrifying organisms, and considers their chief food substance to be *xylane*, or wood-gum, $C_6H_{10}O_5$, isomeric with cellulose but soluble in alkalies, therefore removed by the first alkaline fermentation. This is an additional fact, explaining why the sewage should be properly fermented before entering the final nitrifying filters.[||]

Ampolla and Ulpiani[¶] modify Weissenberg's classification of denitrifying bacteria so as to arrange them under three heads :

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[*] *J. Roy. Agr. Soc.* 1897, III., viii., 577.

[†] *Landw. Versuchs-Stat.*, 1897, xlviii., 247.

[‡] *Landw. Jahrb.*, 1899, 217. Dr. Hugo Weissenberg has also some elaborate studies on Denitrification in the *Archiv. f. Hygiene*, 1897, xxx. 3.

[§] *Deut. Landw. Presse*, 1897, 911.

[||] See *L.C.C. Report*, chapter ix.

[¶] *Gaz. Chim.* 1899, xxix., 1, 49.

(1) Those which destroy nitrites, but not nitrates, namely *Bacterium denitrificans I.* of Burri and Stutzer. (2) Those destroying nitrates but not nitrites—*Bacillus pyocyaneus and* "*Bacterium denitrificans V.*" [and also many of those already quoted from Percy Frankland]. (3) Other denitrifying bacteria which destroy both nitrites and nitrates. From Adeney's and other researches, these are not common.

A large number of organisms found in sewage exert a distinct influence in bringing about nitrification, an influence not confined to the species specially described as "nitrifying," since many which grow rapidly and break up sewage material have the power of inducing or commencing this process if sufficient oxygen be present.

In page 54 I have drawn attention to organisms of this kind isolated by Dr. Sims Woodhead from Exeter sewage. These had been separated by plate cultivation in gelatine, therefore the ordinary nitrifying organism, which will not grow in gelatine could not have been concerned.

Houston, in the *L.C.C. Report*, 1899, records :—

B. coli communis. In 24 hours at 37°C., reduction of nitrates to nitrites well marked (broth 5%, potassium nitrate 0·1%, water 94·9%).

B. mesentericus.

Sewage variety E. Great reduction of nitrates to nitrites in 24 hours at 37°C.

Sewage variety I. No reduction of nitrates, showing the value of the nitrite test for diagnosis.

Dr. Houston also gives *B. frondosus fusiformis*, as negative, *B. membraneus patulus* and *B. capillareus* as active in formation of nitrites from nitrates.

The Massachusetts Report of 1890 (p. 788), states that "an effluent from a sewage filter, where nitrification is *complete*, containing 2% of the total organic matter of the sewage, will not serve as food for bacteria, because it has been worked over already by bacteria in the filter, nearly everything available having been removed."

It would seem, however, from the above, that the denitrifying organisms in presence of nitrates can freely attack this residual organic matter, and that after partial nitrification in a filter, the action of these bacteria which absolutely require a certain amount of organic food converts it into carbonic acid and harmless gases, such as nitrogen and nitrous oxide, taking their oxygen from the nitrates dissolved in the water. I have referred later to the CO_2 evolved in the "resting empty" stage of intermittent filtration.

It has been shown in Chapter III. that the weight of dissolved oxygen in well-aerated river water is approximately 1 part per 100,000. The oxygen-consumed figure in a sewage or effluent will therefore indicate the minimum quantity of river water *alone* necessary to supply the oxygen required to destroy the organic matter. In raw sewages this may amount to as much as 20 volumes. In the raw sewages yielding the effluents referred to in the table below, the oxygen consumed figure was as follows, in parts per 100,000:—

Exeter, 6·56. Sutton, 2·94. Caterham, 14·97.

TYPICAL EXAMPLES OF THE OXYGEN RELATIONS.

PARTS PER 100,000.

	N as Nitrate	O in Nitrate $N_2 : O_5$	N as Nitrite	O in Nitrite $N_2 : O_3$	Total available Oxygen (lowest estimate)	Oxygen consumed	Ratio of available Oxygen to one of Oxygen consumed	Volumes of Oxygen-saturated water required to supplement the available Oxygen.	Percentage of Nitrogen oxidized
Wembley Sewage Farm Effluent, 1896	·75	2·14	heavy	—	2·14	1·79	1·2	0	48·7
Croydon Sewage Farm Effluent, 1895	·88	2·51	"	—	2·51	1·29	1·94	0	63
River Brent, polluted, 1896	0	0	ft. tr.	—	0	2·32	0	2·32	0
Precipitation and coke-breeze filter, Dibdin, 1894	·202	·577	—	—	·577	1·04	·55	·46	—
Tank effluents—									
Exeter, 1896 ...	·041	·117	trace	—	.117	4·32	·027	4·2	1
Ashtead, 1898 ...	12	·343	0	0	·343	9·84	·035	9·5	1
Caterham, 1899...	0	0	trace	—	—	9·25	0	9·25	trace
Coarse bed, Sutton, 1899	·73	2·09	·186	·316	2·41	1·46	1·65	0	27
Filtrates (final effluent) averages—									
Exeter, 1897 ...	·848	2·44	·565	·970	3·41	0·966	3·53	0	33
Ashtead, 1898 ..	6·44	18·4	·03	·051	18·45	0·609	30	0	91·6
Caterham, 1899...	9·0	25·74	·346	·59	26·33	2·71	9·7	0	62
Sutton, 1899 ...	3·33	9·51	·108	·184	9·69	0·83	11·7	0	82

The "available oxygen" is that present as nitrate or nitrite, and the amount of carbonaceous matter requiring destruction is measured by the ordinary figure of "oxygen consumed" as determined by permanganate, since after four hours heating with permanganate no dangerous matter can be left. The table shows that the available oxygen as nitrates and nitrites is in good effluents quite sufficient to deal with the organic matter, even without help from the oxygen dissolved in river water. A large number of the published analyses of effluents are vitiated by the fact that the samples have not been analysed until some days after collection, frequently at the end of a long transit by rail or other conveyance, during which the agitation and inevitable contact with air will have considerably altered the composition in a favourable sense. It is, therefore, desirable, wherever possible, to analyse an effluent within a very brief time from its collection, and the more important determinations should be made on the spot within a few minutes of the discharge. Although this is undoubtedly the only fair procedure, such analyses are not of course comparable with those carried out under the usual conditions which give an apparently higher quality to the effluent, but they demonstrate the existence of the rapid and beneficial improvement in some effluents which I consider, with Adeney, one of the main criteria of safety.

CHAPTER VI.

IRRIGATION AND SEWAGE FARMS.—Broad Irrigation—Soils—Application of Lime or Ashes—Trenching—Organisms in Soils—Suitable Crops—Transpiration of Water—Statistics of Sewage Farms—Systems of Distribution—Ridge and Furrow—Catchwater—Intermittent Irrigation with Underdrainage—Merthyr Tydvil—Calculation of Dilution by Subsoil Water—Irrigation with Previous Treatment—Areas required—General Aspects of Land Treatment.

A partial return to the primitive method of earth-disposal was seen in the adoption of various systems of irrigation. These arrange themselves in three great divisions :

I. *Broad Irrigation*, defined by the Royal Commission on Metropolitan Sewage Discharge as "the distribution of sewage over a large surface of ordinary agricultural land, having in view a maximum growth of vegetation (consistent with due purification) for the amount of sewage supplied."

II. *Irrigation with Copious Underdrainage*, classified by the same Commission as "Filtration," and defined as "the concentration of sewage, at short intervals, on an area of specially chosen porous ground, as small as will absorb and cleanse it ; not excluding vegetation, but making the produce of secondary importance. The intermittency of application is a *sine quâ non* even in suitably constituted soils, wherever complete success is aimed at."

III. *Mixed Systems, including previous Sedimentation or Chemical Preparation.*

It will be convenient to call these shortly the *broad*, the *intermittent*, and the *mixed* systems of irrigation. All of them are popularly known as "sewage farm" schemes, and are jointly saddled with the following difficulties :—

(1). The unsuitability of the only land often attainable.

(2). Local opposition, and the very high prices generally demanded for the area.

(3). The failure, under these conditions, of making the sale of the produce remunerative.

Therefore, in a large number of cases it has been found impossible to dispose satisfactorily of sewage by irrigation methods. In any of these systems, according to Bailey Denton, "the land chosen should be so situated in relation to the town that the sewage should flow to it by gravitation, pumping being costly and greatly reducing any profits that may arise. The rent to be given should not exceed £2 10s. per acre."

Broad Irrigation.—This method requires a very large extent of land (estimated officially as one acre per 100 of population), since it chiefly depends on the *surface* for purification, and on the action especially of the nitrifying organisms, which, as we have seen, require air, and therefore do not work well in the depth, disappearing altogether at a certain distance below the surface. R. Warington tested for nitrifying bacteria in the heavy soil at Rothamsted by their power of nitrifying weak urine. Out of 39 samples taken at various depths down to 3 feet, all but one were active; at 5 feet, half were inert, and below 6 feet the organisms seemed to be absent. He concluded that the action only extended to 18 inches in clay, though to a greater depth in sand, and that, besides the scanty aeration, the deficiency of phosphates in the lower layers adversely affected nitrification. The same soil which rapidly nitrified when in a moist, aerated condition, became a vigorous denitrifying medium when water-logged. Dr. Sims Woodhead* points out that in soil very near the surface the number of anaerobic organisms as compared with aerobic was found to be comparatively small; deeper down the proportion of anaerobes was much larger, "until we come to a layer in which practically only anaerobic bacteria are found, while deeper still there may be no organisms of any kind."

For these reasons the sewage is preferably made to pass obliquely, by digging deep trenches at the lower end of the farm.

When, owing to the geological structure of the ground, the liquid can rise again at a lower end as springs, the absence of the first nitration may be concealed by a second process occurring as it approaches the surface, approximating to the method of upward filtration.

Sanitarians are usually averse to any system which does not include subsoil drainage. When, however, an area at a distance from habitations, with a porous soil (especially under rice cultivation, as in India) is available, broad irrigation may be applied, ditches and intercepting drains being provided, and all wells on the sewage area, or within a radius likely to be affected, being closed.

As to the efficiency of soils, while it was originally held that the "cleansing power" of a soil was determined solely by its physical condition, porosity, freedom from clogging, water-retaining power, etc., at the present time we know that the chemical composition and bacterial efficiency modify the results. Thus Dr. Frankland in 1870, in reference to a soil from the sewage farm at Barking, says, "These highly remarkable results show that there are soils in which the process of nitrification either does not take place at all, or goes on with great difficulty," and with regard to a loam from Dursley in Gloucestershire he found that it surpassed all others experimented on in its power of purifying sewage, as it had a cleansing power of nearly 100,000 gallons per acre per day. Although at that time the chemical composition of the soil was believed to have no influence on the result, the Dursley soil above referred to contained as much as 8·1 per cent. of carbonate of lime, whereas that at Barking contained under 2 per cent., and we now know that the presence of carbonate of lime or of gypsum is favourable to the growth of the nitrifying organisms.

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* *Baltimore Sewerage Commission*, 1899, p. 105.

In a recent inquiry in which alternative sites were available for a sewage farm I obtained the following results :

	A.	B.	C.
Percentage of water	6·75	1·90	3·05
Parts of nitric nitrogen produced per 100,000 parts of soil in 5 days on dilute urine	·168	·504	·36

showing that the least water-logged soil, B, was also the most active bacteriologically. With effluents which have been chemically treated with lime, there may be sufficient alkaline base to favour the growth of the nitrifying organisms, even when the soil or the filter bed is devoid of such base.

In an analysis of samples of soil from a sewage farm in Surrey, where the soil, a ferruginous sandstone, is very deficient in lime, the calcium carbonate had increased by the treatment of the land with sewage, and thereby the quality of the effluent or purification was increased.

	I. Land before treatment.	II. After 18 months. Field I.	III. After 18 months. Field II.
Moisture	10·96	13.56	14·20
Mineral Matter	80·34	82·76	81·04
Organic ,, ...	8·70	3·68	4·76
	100·00	100·00	100·00
Lime	0·224	0.54	1·23
Equal to Ca CO_3	0·40	0·96	2·20
Organic Nitrogen	0·064	0·193	0·230

Both a mechanical and chemical analysis of samples of soil is necessary for judging as to the suitability of proposed sites.

The most unsuitable conditions are stiff tenacious clays, peaty or boggy ground, and coarse gravel with hard conglomerated layers. In India, where the temperature is higher, the growth continues for a longer time in the year, and the sewage is weaker and less voluminous than in England, a less area per person is found requisite ; thus Jones* recommends at least 1 acre of good soil for 500 persons at 15 gallons per head, while Prof. Robinson gives the average of English sewage farms as 149 people to each acre irrigated with 38 gallons of sewage per head per day. Even this is too small an allowance, as the Local Government Board prescribes for stiff clay 1 acre for every 25 persons, and for loamy gravel 1 acre for 100.

The application of lime is found advantageous ; at Berlin, on a sand subsoil, 1 to 2½ tons of "waste lime" per acre have been spread with benefit over fields previously drenched with sewage. For clay, ashes from the town refuse are dug or ploughed in. Deep steam ploughing and even subsoiling to turn in the sludge is at intervals necessary, since crude sewage discharged direct on land rapidly coats it with a felted layer of black decomposing matter, which hinders the access of oxygen, chokes the plants, and soon creates a nuisance.

In broad irrigation there is always a risk that a portion of the raw sewage may escape wholly unpurified. On clayey soils the liquid passes almost entirely over the surface, but this, if a sufficient distance be given, has been found to effect a great purification, with, however, generally a nuisance. The mere deep trenching of heavy soils, laying pipe drains, and filling up with ballast, etc., results in an almost unoxidized and very impure effluent. The same result occurs from the production of cracks in clay by drying, or from the fissures so common in chalk formations. A case occurred at Beverley,† in Yorkshire. The top layer of clay had become extensively cracked in the summer, allowing the raw irrigation sewage from the East Riding Lunatic Asylum to reach the chalk beneath, whence it travelled through fissures about half-a-mile to a deep well that was a portion of the water supply of Beverley.

Dr. Houston has counted the number of bacteria and spores present in 21 different soils. Among them he finds—

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* *Manual of Hygiene*, 1896, p. 484.

† For another illustration on sandy soil, see Chapter I., p. 12.

		Organisms per gramme of soil.
1.	Sandy soil near the sea	8,000
2.	Suburban garden soil, not recently manured ...	518,000
3.	Dark garden soil, manured six months previous	795,000
4.	Light-colored soil, not recently manured or disturbed	1,051,000
5.	Black loamy soil, occasionally having farmyard manure	1,084,000
6.	Rich heavy clay, periodically manured ...	2,531,000
7.	No. 3 above, after recent manuring	3,308,000
8.	Garden soil treated with human fæces and urine for six months previous	26,780,000
9.	Sewage field—from a trench along which sewage had been running a short time before ...	115,000,000

Virgin soils did not contain *B. coli communis* or its allies.

Dr. Sidney Martin has investigated the vitality of *B. typhosus* in soils. He proved that while in virgin soils it attenuates, and after a short time disappears, in those which contain large quantities of organic matter, particularly from sewage, it will multiply even through extremes of heat and cold (from 37° to 3° C.), and under conditions of dryness, and will survive for at least 450 days alone, or 50 days in presence of other bacteria.

It will, therefore, be seen that although, as pointed out elsewhere, no injury to health has been directly attributed to sewage farms, the possibility of the survival or even the multiplication of pathogenic organisms on such farms must be taken into account when the drainage waters pass into or near drinking-water supplies.

SUITABLE CROPS.

On a sewage farm the conditions are different from those of ordinary agriculture, inasmuch as although the liquid undoubtedly contains the elements of plant food they are supplied too continuously and in too great dilution with water, while the volume is usually greatest at a season when it is absolutely injurious to crops. Therefore for successful cultivation the plants must only receive the sewage as they want it, the remainder being treated by other methods. It is also necessary that the plants should be of such a character as can be grown on a ridge so as to prevent the liquid at any time flooding their growing tops.

Déhérain* has determined the quantity of water exhaled in one hour by certain growing leaves exposed to the sun.

**Chimie Agricole*, p. 281.

Plant	Temperature of the Air.	Weigh of water transpired by 100 parts of leaves.		
		I.	II.	III.
Colza	25° C	1·3	1·5	1·0
Ditto	36°	12·0		
Wheat	19°	74·2	71·8	
	28°	88·2		
Rye...	36°	100·	99	92

Therefore in one hour a young leaf of a cereal evolves about its own weight of water.

Hellnegel and Wollny found that 233 to 912lbs. water were transpired for every 1lb. of plant tissue formed. It varies with the amount of leaf surface and length of growth, and is greatest in clovers and grasses and least in roots and potatoes.

Sir J. Lawes estimated that 250 to 300 parts of water are evaporated for every one part of dry solids elaborated by the plant.

Other observers have confirmed the fact that the transpiration of Gramineæ (grasses and cereals) is greater than other plants, hence they are indicated as absorbing a larger quantity of sewage. At the Berlin sewage farms the proportion grown is, in acres, cereals 3,000, grass (rye grass and Timothy) 2,000, root crops 1,000, oil seeds (colza, etc.) 250, with rotation.

Italian rye grass is always mentioned in the first place since the report of Rawlinson and Read to the Local Government Board in 1876, that it " absorbs the largest volume of sewage, occupies the soil so as to choke down weeds, comes early into the market, bears five to seven cuttings in the year, and produces thirty to fifty tons of wholesome grass per acre."

Rye grass exhausts itself in about three years, when it is ploughed up and replaced by root crops (usually mangolds), or cabbages (Beddington), with a return afterwards to rye grass. Mangolds yield a heavy but rather watery crop. Wheat and oats are stated to run to straw, rather than to grain. Leguminous plants, which are capable of taking up nitrogen from the air, are not adapted for an object which aims at reducing the organic nitrogen. The Report of the Royal Agricultural Society on the Bedford Sewage Farm, mentions one plant, " Prickly Comfrey," useful for horse fodder, " which it seems impossible to damage by sewage, as it was completely flooded for three weeks in succession, with benefit, and yielded three crops in a year."

Celery also flourishes, and sunflowers have been successful. Generally the plants that are found to suit best are those that are commonly grown in the neighbourhood.

At Berlin, before reaching the grass plots, the sludge is removed by catch-pits, as it is found that a coating of sludge interferes with the growth. For cereals and seeds it is not strained, but they are only sewaged while the crops are underground, so that the sewage does not come in direct contact with the plant. Roots and grass are irrigated all the year round.

Comparative analyses of drainage waters from land receiving raw, and chemically treated, sewage show that nitrification takes place more rapidly with the latter, as probably the felting of the solids on the surface prevents air from passing into the soil for oxidation when the untreated raw sewage is passed directly on the land.*

Osier beds are often planted, and act partly as strainers; watercress and many aquatic plants have been found useful.

Into the financial aspect of sewage farms I cannot enter, but it is recognised that while with careful management the sale of produce may be made to yield a small balance over working expenses, if the repayment of the capital (estimated to be about five times that required for an ordinary farm) were considered, the profit would be turned into a loss.

Some statistics of Sewage Farms as published in 1896 are given on p. 112.

Systems of Distribution.

1. *Ridge and Furrow.*—The land is laid out in beds, with ridges 40ft. apart sloping 20ft. on either side at an incline of 1 in 50 to 1 in 150 to furrows in the centre. From a transverse main carrier at the upper end, the sewage passes into distributing channels on the ridges, whence it flows in a uniform layer down the slopes, any not absorbed running from the furrows into a lower plot. The distributing channels (with the ridges) have a longitudinal slope of 1 in 600 to 1 in 300. The main carriers must be lined; the channels may be dug in the soil.

In many places, the land is laid out by the ridge and furrow system in a different way, the sewage being fed along the furrows with the vegetation on the ridges, and the underdrains between, so that the liquid reaches the roots from underneath, the excess passing laterally to the drains. This method seems to be recog-

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*For an interesting example *vide* Ashton, *Treatment of Wigan Sewage*, Trans. Inst. San. Eng., Nov. 1899; see also chap. vii. p. 130.

SEWAGE FARMS.

Place.	Population.	Area of Farm: Acres.	Area under Irrigation.	Subsoil.	Sewage: gallons per 24 hours.	Acres under intermittent.	Additional previous treatment of Sewage.	Inhabitants per acre irrigated.
Aldershot	12,000	8	8	Loamy sand ...	389,000	0	Al. sulph. and lime	1,500
Banbury	12,700	...	155	..	450,000	...	...	82
Bedford	25,400	223	130	Loam and gravel ...	1,000,000	0	0	193
Burton-on-Trent ..	46,400	556	430	Gravel	5,000	130	Lime	108
Cheltenham	49,000	...	360	...	1,000,000	...	...	136
Crewe	35,000	...	257	...	1,378,000	...	...	136
Croydon	114,000	...	565	...	4,500,000	...	..	201
Derby (West)	40,400	...	207	...	1,100,000	...	..	195
Doncaster	23,600	278	...	Light gravel ..	500,000	0	0	85
Leamington	27,000	...	350	...	770,000	...	...	77
Norwich	106,000	...	309	...	4,500,000	...	.	343
Oxford	50,000	370	335	Sand and clay ...	1,300,000	32	0	149
Reading	65,000	...	350	...	1,500,000	...	...	185
Tunbridge Wells ..	30,000	...	310	...	800,000	...	...	96
Warwick	12,000	285	265	Clay gravel	750,000	0	Settled	42
Wigan	59,000	...	420	...	1,250,000	...	...	140
Wimbledon	25,000	73	73	Clay and some gravel	600,000	0	Rough filtration and chemical treatment	342
Wrexham	12,000	42	84	Drift gravel... ...	400,000	2	Settled	143
Berlin (1890)—								
Osdorf ...	1,600,000	19,000	11,000	Sand	30,000,000	Part	Part settled	198
Gross Beeren								141
Falkenberg								165
Malchow ...								122

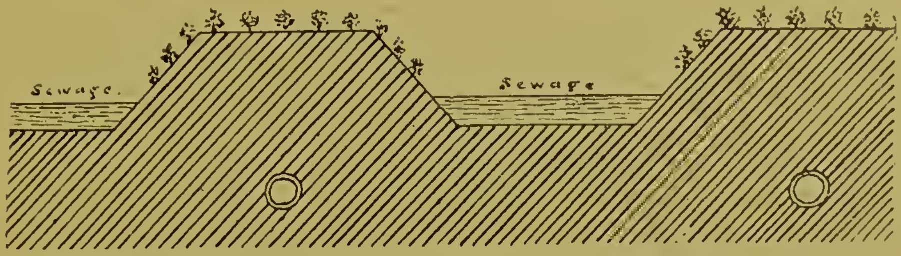

FIG. 14.—SECTION SHOWING UNDERDRAINS IN RIDGE AND FURROW IRRIGATION.

nised as the best for avoiding water-logging, "sewage sickening," and other evils of sewage-farming by broad irrigation. It must be remembered that the reliance is here on the filtering qualities of the soil, the plants playing a subordinate part in utilizing the nitrogen of the soil afterwards.

At Paris, a portion of the city sewage is treated in this way at Gennevilliers and Achères. At the former the soil is sand mixed with clay, and the crops are various, but chiefly vegetables, with also fruit trees, flowers, and some meadow land. The irrigation is managed by flooding at intervals, the vegetables growing on ridges as described above. Part is worked by private lessees, and part by the State, and the results seem to have been satisfactory until lately, when, owing to the increase of population and greater volume of sewage, complaints have been made to the municipality of flooding and nuisance.

At Milan the sewers join in a canal, the Vettabia, which discharges into about 4000 acres of land arranged in terraces, the final effluent falling into the river about ten miles below the city. The proportion of sewage applied is calculated as that of 40 persons per acre of land.

At Dantzig, Breslau, and other places on the continent, sewage farms are also at work, but almost invariably on light soil.

2. *Catchwater.*—On irregular ground, an upper main carrier is made 1 to 2 feet wide and 6 to 10 inches deep. The sewage overflows from it at any point by temporarily damming, and after spreading over the ground, the excess collects in a lower catchwater gutter made to the contour of the land, from which it is dammed and released on the same principle. This method requires much control.

There is evidence that growing plants, especially of certain species, are capable to a certain extent of absorbing, and using for their food, the organic and ammoniacal constituents of raw sewage. By means of the numerous enzymes secreted by plants they are able to dissolve and utilize the organic suspended matter. But under ordinary circumstances, vegetation absorbs most of its carbon from the air, and its nitrogen from nitrates, and requires its food to be well prepared before it can assimilate it. Especially does excess of ammonia act unfavourably. S. Cloetz found that 10 parts of ammonia in 100,000 (a strength not uncommon in sewage) was injurious.

Déhérain * states that salts of ammonia act most unfavourably on vegetation, and that soils which had received a dose of them "un peu forte" remained sterile for several years.

In the ditches conveying sewage that used to be so common, and even in the open drains from cottages, it is noticed that the channel remains black and barren till the sludgy solids have had time to deposit or become fermented, and the soil to reassert its action, when the liquid clears and loses its odour, and a copious growth of vegetation arises. Therefore, in cottage gardens and allotments, the sewage is not applied to the ground till it has been dissolved and fermented in pits or cesspools. Such a process, when scattered over a neighbourhood, is sure to create a nuisance, but carefully managed, and conducted collectively in special large areas, it has proved to be fairly successful, as Dr. Poore describes.

The main faults of irrigation with raw sewage are, therefore—

(a). Choking and felting of the surface by organic slime.

(b). A surplus of unprepared organic matter, and of ammonia, over the wants of the plants.

(c). In consequence of the above, a deficiency of oxygen and of healthy action in the body of the soil.

(d). Great inconstancy owing to season, temperature, and cultivation.

The faults *(b)* and *(c)* are avoided to a great extent by the second system, that of—

II. *Intermittent Irrigation with Copious Under-drainage,* which is really using the land as a partially regulated bacterial tank and filter. If properly arranged, the drains act also as aerators, so that the soil is more thoroughly supplied with oxygen, allowing nitrification to proceed more actively, and to greater depths. At Merthyr Tydvil, in 1871, "twenty acres of a porous soil drained from 5 to 7 ft. deep, were arranged by Mr. Bailey Denton in four series of beds ; and over each series in succession the drainage water from 50,000 inhabitants, more than one-third of whom were connected with the sewers, was poured for six hours at a time," by the ridge-and-furrow system, with intervals of 18 hours per day for rest and aeration, crops of cabbages being grown. The works were designed to realize on a large scale the experiments of Sir E. Frankland in the laboratory of the Royal Commission. It is reported that the crops at Merthyr were healthy and luxuriant, and were valued, in 1872, at £42 to £45 per acre, also that no nuisance had arisen. As to the effluents, from the analyses made by Sir E. Frankland, in 1871-2 I have calculated the following averages, adding also his "proposed standards of purity."

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* *Chimie Agricole,* 1892.

	Dissolved Solids.	Organic Carbon.	Organic N.	NH_3	N as Nitrates and Nitrites	Total Combined N.	Cl.	Suspended Solids.	
								Mineral.	Organic.
"Proposed Standards" ...	None	2·0	0·3	None	None	None	None	3.0	1·0
Sewage after liming	52·0	2·44	0·9	2·7	·017	3·18	5·98	11·8	21·6
Filtrate	33·2	0·14	0·03	·063	·273	·348	2·74	trace	trace
Subsoil water ...	19·4	.106	·011	·004	·061	·075	0 9	—	—

It is important to notice that in the use of land by any system there is always a variable dilution with rain and subsoil water, so that the improvement effected by soil, as indicated by the quality of sewage and effluent, would appear to be greater than it is, unless we take this feature into account. Frankland* applies the formula

$$x = \frac{a + c}{c + b}$$

"in which a, b, and c represent the amount of chlorine in 100,000 parts of sewage, subsoil water, and effluent respectively, and x the required volume of the subsoil water which has thus become commingled with each volume of the original sewage." Calculating from his results, he finds that each gallon of the sewage had become mixed with from 1·9 to 2·2 gallons of subsoil water. His figures, therefore, show that the sewage has undergone dilution with more than its volume of subsoil water, and probably with some rain, as the mean dissolved solids of the sewage and subsoil water are about the same as those in the effluent, while the chlorine in the effluent is less than half that in the

* *Experimental Researches*, p. 763.

sewage. But even with this allowance the result justifies Frankland's statement that "the effluent water on all occasions was purified to an extent much beyond that required by the standards of pollution suggested by us as those below which refuse liquids should not be permitted to enter rivers." The analyses are of further interest at the present time, as we can see from them that:—

The reduction of the total nitrogen by about 75 per cent. (making allowance for dilution), is not accounted for by the somewhat meagre production of nitrate and nitrite.

Since the sewage "gradually sank into the soil as it flowed," this improvement can only be partially due to volatilization of free ammonia, of which soils, as is known, are very retentive.

The large reduction in organic nitrogen was doubtlessly occasioned in part, at first, by its absorption by the soil, but as the analyses extended over nearly a year and a half, and the later ones showed the same changes, this mechanical absorptive action is of minor importance.

The explanation is to be found in the life of the bacteria growing in the soil, and acting by the process described elsewhere as *denitrification*, in which a large quantity of free nitrogen and lower oxides of nitrogen is generated from both ammonia and organic matter, and evolved as gas. In fact, the whole process, instead of being, as it was considered at the time, partly mechanical and partly chemical, was in its essence bacterial.

Frankland, however, as he admitted, was dealing with an exceptionally weak sewage, and over-estimated the efficiency of the process when he stated that "the application of the sewage of more than 1000 persons to an acre of land is consistent with the growth of crops and a superabundant purification of the effluent water, and that the sewage of a much larger number could be effectually purified on an acre if the growth of crops were given up." The Local Government Board, on the other hand, prescribes "for intermittent filtration without precipitation, through sandy gravel, one acre for every 100 to 300 persons."

Experience has not shown any danger to health either from sewage farms or their produce.

III. *Irrigation with Filtration or Precipitation.*—From the faults and difficulties we have mentioned it is rare for any sewage system to depend on the land solely. Even in the Merthyr Tydvil trials a previous treatment with lime was used. Bailey Denton says that "the sewage should invariably be passed in its crude state through a simple filter composed of gravel, coke, broken ballast, or some other suitable material, before being applied to the land." Such a "roughing filter" is almost universally used, and often by itself effects considerable bacterial improvement in proportion to the time the liquid remains in contact, although its functions are primarily to strain off the solids.

At Leicester, according to Mr. Mawbey,* they succeeded in dealing with the sewage by broad irrigation on clay land by first clarifying it by coarse banks of clinker of ¾ to 2 inch size from the refuse destructor, but a bacterial scheme is now under consideration.

It must always be remembered that the solids are an integral part of sewage, and that their removal, entirely, or in part, by any system of straining, settlement, precipitation or filtration, is only an evasion of the main question, and results in the production of a "sludge" which has to be separately treated.

Precipitation, if the effluent is afterwards to be applied to land, must not involve the use of any chemicals which may cause injury to vegetation. Iron and aluminium salts, such as alumino-ferric, if followed by lime, give a much-purified effluent which has proved to be innocent in agriculture, although both this, and simple sedimentation or filtration. remove from the liquid some of the constituents which, when properly fermented, are capable of assimilation by plants, and also, along with the suspended solids, many of the bacteria which effect these changes.

In 1893, the President of the Local Government Board, stated that it has been the practice of the Board "to decline to sanction a loan for any scheme of sewerage or sewage disposal unless it provides that the sewage shall be purified by being passed through the land before being discharged into a river or stream to which the Rivers Pollution Prevention Acts apply. They consider that the requirements of those Acts would be contravened unless the sewage is so purified.

"The Board are fully aware that by means of chemical and mechanical treatment very much may now be done to aid in the purification of the sewage, and they therefore approve of a very much less area of land being provided when the Authority propose to adopt such treatment ; but *they are now of opinion that these means alone, without the passing of the sewage through land, are insufficient.* Delay has in some cases been occasioned where sanctions to loans have been withheld pending arrangements being made for the acquisition of land." This is practically the present view of the Board, and the appointment of the Royal Commission in 1898, was mainly due to the strong opposition of many of the more important local authorities to this rigid view on the question of final land treatment.

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* Society of Engineers, Dec., 1898.

The areas of land that have thus, in the past, been officially demanded in England for the purification of sewage according to the process adopted, are as follows; it must, however, be remembered that a much less amount is often used successfully with proper management and care, and on the other hand local conditions may even demand larger quantities.

POPULATION PER ACRE OF LAND.

1. Irrigation without precipitation—	
Stiff clay	1 acre for every 25 persons
Loamy gravel	,, ,, 100 persons
2. Intermittent filtration without precipitation—	
Sandy gravel	1 acre for every 100 to 300 persons
3. Irrigation and precipitation—	
Clay	1 acre for every 200 persons
Loamy gravel	,, ,, 400 persons
4. Intermittent filtration and precipitation—	
Sandy gravel	1 acre for every 500 to 600 persons
5. Precipitation and filtration through specially prepared filters, followed by irrigation—	1 acre for every 2,000 persons

In the construction of special filtration areas, the Local Government Board at present require that provision shall be made for

(1) A rainfall and sewage calculated at three times the dry weather flow.

(2) Above three times and up to six times to be treated on a further special area of storm water filters, and not until the flow is above six times may it be discharged into a stream, or on to prepared land without passing through the filters or other method of treatment.

(3) The capacity of the filters to be taken at one-third for the fluid and two-thirds for the filtering material.

(4) A cycle of eight hours for filling, emptying, and rest for aeration.

It will be seen, therefore, that as land in most cases will receive the effluent before it passes into the natural drainage waters of the district, local conditions will in the future, as in the past, determine how it can best be utilized for this purpose.

In any system of sewage-farming the difficulties of controlling the drainage area, so as to provide for the varying amounts and qualities of the sewage, will always exist. If the land be sufficiently porous and well drained to prevent its being water-logged and to allow the free passage of the effluent during wet seasons, in dry weather it will permit it to run through too rapidly, and the effluent will not be purified. A denser soil, adapted for ordinary weather, will be entirely clogged by unusual rains, and therefore unsuited for any broad irrigation scheme, unless a very large area is available.

The strongest argument for sewage farms and irrigation must always be the restoration to the land of the matter taken away from it, without which there must be a continual impoverishment. This aspect of the question was recently brought into prominent notice by Sir W. Crookes.* I point out in later chapters how, under graduated bacterial purification, an effluent containing practically all the nitrogen, phosphates, and other mineral constituents, is obtained in a condition suitable to be returned to the soil without loss, and available for plant life.

For the object of purification only, the insistence on final land treatment is decidedly a mistake, as where a proper process is used, no further purification will be necessary; indeed, in many instances, as at Hampton, an originally good effluent suffers great deterioration by subsequent passage through land. In addition to the cost of purchase of land, and the difficulty of securing a suitable site, in many cases, as the sewage in passing through the filters falls 6 or 8 feet, the expense of pumping may have to be added.

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* *B.A. Reports*, 1898.

CHAPTER VII.

SUBSIDENCE AND CHEMICAL PRECIPITATION—Screens—Settling Tanks—Roughing Filters — Clarification — Lime — Aluminium Sulphate — Ferric Sulphate — Ferrous Sulphate—Alumino-ferric—Sludge: its composition, volume, and disposal.

Mechanical Separation is used as an adjunct to many processes. The larger solid matters of sewage admit of a broad classification, according as they are mainly inorganic or organic.

(1) *Grit and detritus*, small stones and sand, are carried down largely by sewers of steep gradient, or in periods of storm. Under the *combined* system, in which road sweepings, washings of land, &c., are included, they will be always present, but even under a *separate* system, intended to take only excretory and household waste, they cannot be entirely avoided.

Being heavy, and almost entirely inorganic, they are removed by settlement without nuisance, since any entangled organic matter rapidly disintegrates as in gravel soil. In towns, a part is collected in the street gullies (p. 7), a further quantity in sumps in the line of the sewers, and the remainder in a grit chamber at the entrance of the sewage works. Processes using mixing machinery require careful removal of hard matters.

(2) *Organic Residues*—vegetable, fæces, paper, fibres, wood.—These in great part float, owing to lightness, or to gases generated by fermentation. Their inclusion or exclusion constitutes a main difference, as we shall see further, between some modern methods of ultimate treatment. The question as to whether a sewage is dealt with strained, settled, or absolutely raw, is a matter of very great importance.

Screening off the coarser solids is used in several places to prevent the clogging of filters. Gratings or meshes of different widths are employed, either cleared at intervals by hand labour or continuously by various automatic contrivances. One of the most effective is that adopted at Sutton, which consists of a revolving wire drum, rotated by a paddle wheel moved by the current of sewage. The amount of solid matter thus avoided in the Sutton treatment is not stated, but from the figures given at Leeds it

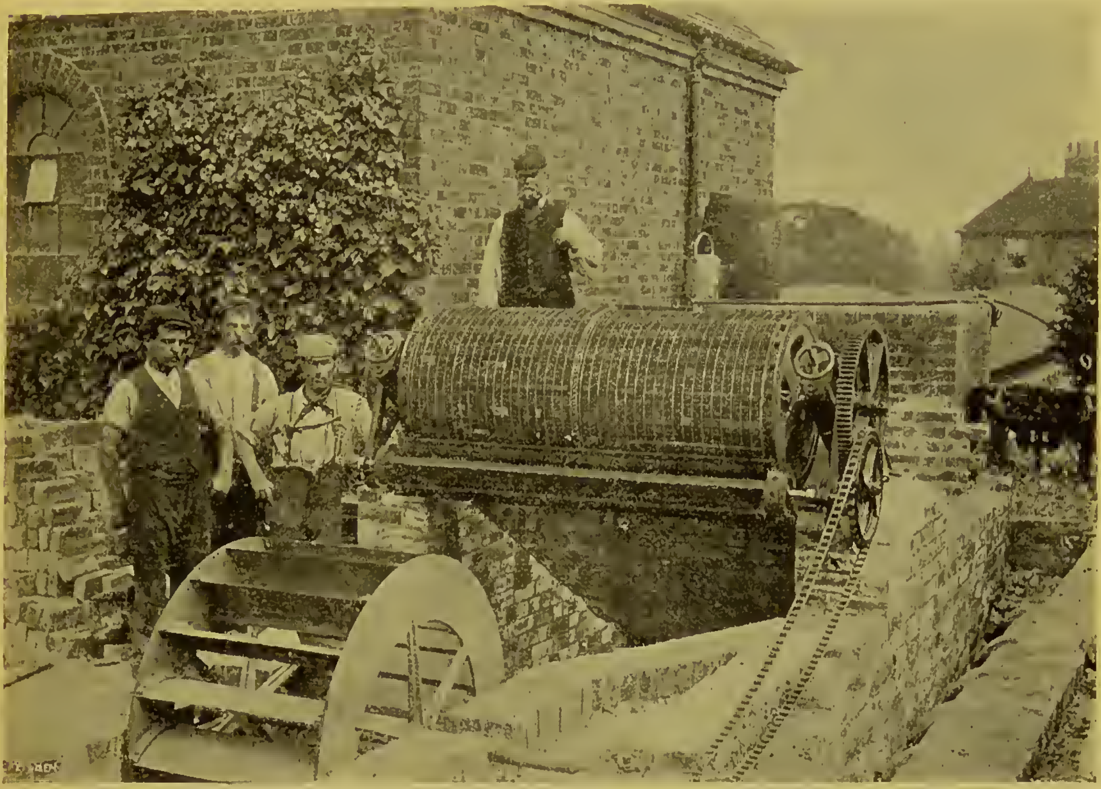
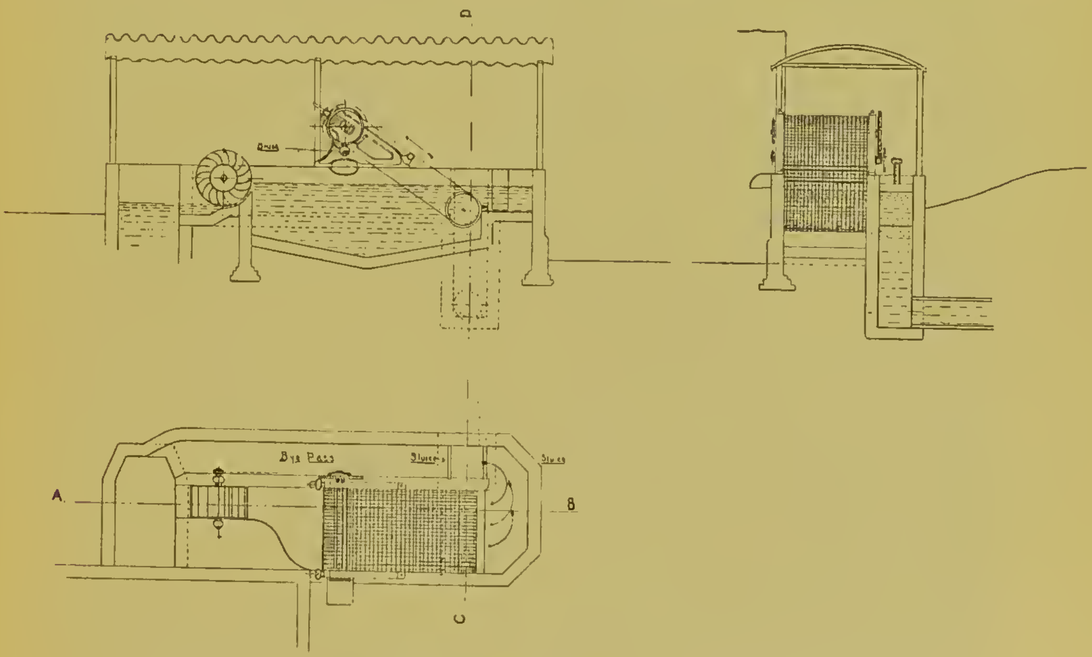


FIG. 15.—ROTARY SCREEN FOR CRUDE SEWAGE AT SOUTHALL SEWAGE WORKS, ISLEWORTH.



D
Drum
Bye Pass
Sluice
Sluice
A
B
C

FIG. 16.—PLAN OF ROTATING SCREEN FOR RAW SEWAGE (J. SMITH & CO., CARSHALTON).

is estimated at 30 barrow loads per day per million gallons. Taking a barrow load as 1½ to 2 cwt., this would total up to 2 or 3 tons per day per million gallons of matter which consists mainly of paper, lumps of fæces, and vegetable residues, requiring separate treatment.

These screens should be in duplicate: some have been made with sharp edges to cut up the organic matter.

For the interception of greasy floating matter, which is often a great difficulty, two systems are adopted, one of separation by grease traps, the other as at Nuneaton (part of Cosham's process) of breaking it up into an emulsion with lime or other materials for subsequent treatment. At Bradford, and other towns, where there is a large quantity of wool-scouring refuse, it has been suggested that the grease be extracted with sulphuric acid, afterwards using lime for neutralization, and other special methods are in use at Roubaix in France, and elsewhere, by which the fat, when extracted, can be utilized for making lanoline or soaps. (See Chap. XII.)

The grease from ordinary soap-suds does not seem to admit of profitable extraction, as the fat is so much contaminated with other organic matter.

The amount of suspended matter in sewage is greatly influenced by its history before arrival at the works. Where the sewers are long and have a varying gradient, much deposition and dissolving may occur. When the sewage has to be raised to a higher level, the pumping causes some of the organic matter in suspension to disintegrate, and thus renders it more easily soluble. Agitation with pulverization of the organic solids has been the subject of many patents.

In the "Ives" patent (16724, 1894), the sewage, entering a circular screening chamber at a tangent, whirls the paper, excreta, and other solids against baffling plates, by which they are to a great extent comminuted.

At Davyhulme, Manchester, according to the City Surveyor's Report for 1897, the "ashes, clinker, sand, and other heavy insoluble matter brought down with the sewage" was up to that time deposited in the precipitation tanks, from which it had to be removed by manual labour at considerable cost. "The bulk of the insoluble material comes down in periods of flood—sometimes as much as 300 tons are left in the tanks after one flood." To remove this difficulty, additional works were constructed, comprising catch-pits in duplicate, with movable coarse screens "to intercept large solids which might cause damage to the machinery," the screens being balanced by weights so that they could be raised for cleaning. Finer screens were fixed at the outlet, with mechanical rakes to keep them free from rubbish.

A storm-water overflow was provided between the two sets of catch-pits for times of flood, and penstocks for the diversion of the sewage through either set of strainers.

The London sewage is screened through iron gratings "on account of the large amount of floating substances passing through." In 1897 it was stated that the quantity of solid matter extracted by the double set of gratings was between 80 and 100 tons per week. A destructor furnace built close by was used for destruction of the refuse. Screening is also mentioned at Friern Barnet, Oldham, Swinton ("strainer with cleaning rakes attached"), Glasgow ("wrought-iron grid to catch heavy and floating matter"), Accrington ("screening chamber where detritus deposited, with wrought-iron grid to prevent floating and large substances from passing into the precipitation tanks. A revolving fork arrangement cleans the screen by lifting the deposited material to the surface. The chamber has also a hopper dredger for removing the detritus that accumulates at the bottom"), Kingston ("Native Guano process"), Launceston ("ferrozone and polarite"); in fact all places and systems except those with a preliminary hydrolytic tank find it necessary to separate the coarser organic matters mechanically.

Roughing Filters.—One of the most elaborate is Col. Waring's, used in the first stage of his system, as employed in the United States. A ten-inch suction pump, running full-bore, delivers the solids and liquids on to a shallow bed of broken stone, divided by a vertical partition: when one side became choked the other was used. From this it passed into "strainers" of stones, pebbles, and coarse gravel. Although it is claimed that the "function of the strainers is merely mechanical sedimentation," they also perform a bacterial office, as can be judged from his report. All materials used, stones, broken brick, coal, ballast, or large coke, exert at first simply a mechanical action, but after a time develop coatings of organisms which greatly extend their effect. The Massachusetts Report stated that "with the gravels and sands, from the coarsest to the finest, we find that nitrification takes place in all, when the quantity of sewage is adapted to their ability, and the surface is not allowed to become clogged by organic matter to the exclusion of air."

SUBSIDENCE OR SEDIMENTATION.

After any method of straining, sewage remains turbid from a large quantity of suspended matter. Its composition of course is variable, but frequently, as shown in the second chapter (p. 23), it contains about one-third of the organic nitrogen and half the carbonaceous matter of the sewage. With turbid waters, and also to a certain extent with effluents and very weak sewages, it has been proved that settlement in reservoirs or tanks can bring about a great improvement. But with raw sewages it is different, as their fermentation keeps the organic matter in suspension, and any prolonged storage in open receptacles creates a nuisance. The deposition has been aided and accelerated in various ways. Clay, ashes, or charcoal, thrown in and mixed, will settle down, and by entangling the solid impurities, will produce a clarified liquid. In fact, settling basins were formerly almost the only means of clearing a strained sewage, the deposit being at intervals cleaned out and thrown on land, or even into the nearest ditch or watercourse.

Numerous patents have been taken out for slight variations in the use of blast-furnace slag, clay, or shale alone, either raw or burnt, with lime, peat, charcoal, coke, etc.

Any system of separation of solid matter from sewage results in the formation of "sludge," which, in mechanical methods, is the greater in amount as the straining medium is finer. Whatever material is added as a precipitant must also increase the volume. The great difficulty in dealing with sewage sludge is its bulk, containing as it does 92 to 98% of water. If it be tried to obtain it in a denser condition by longer deposition, obnoxious gases are certain to be produced. Where suitable land is available, the strained sludge is dug into the soil when sufficient earth is present to absorb the liquid. But this resource is liable to exhaustion, and in most cases other means have to be resorted to.

One of the suggestions for the utilization of sewage sludge was "for filling up low-lying land, putting its value at the lowest possible amount."* It was not found, however, at all suitable for the purpose, owing to its density and wetness, its unsanitary character, and the large area of land required.

In 1886, following the application of destructor furnaces at Southampton and Ealing, a series of experiments were carried out at Leyton and Cardiff, with the object of proving that it was

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*L. Flower, *Royal Commission on Metropolitan Sewage*, 1875.

possible to burn sludge remuneratively and without offence. A certain amount of coal was of course used to dry the cake, the ammonia evolved was collected, and the volatile matters passed through the fire. It was claimed that the coke produced paid for the coal and working expenses, and that the nett cost of incineration did not exceed sixpence per ton.

Numerous similar inventions were put forward about the same time, founded on the hope that this material could be profitably utilized, either as manure, or by chemically extracting some of its constituents. But it was found that the agricultural value was so disappointing that farmers refused to take it, while in any combustion process the water must first be removed by pressing and heat, so that the cost of machinery and fuel absorbed all the profits.

Abandoning the idea of remunerative working, the next object was to secure removal without nuisance, and the sludge was compressed in filter presses of various constructions to a cake containing 25 to 50 per cent. of water, sometimes previously mixed with lime or other substances to facilitate the pressing. The cost was still great, and the product nearly worthless. The following are analyses of two examples :

	Native Guano Co.'s Sludge Manure, Crossness, 1872.	Pressed Sludge Cake, Crossness, 1886.
Water	26·45	58·06
Organic Matter	16·16	16·69
Alkaline Salts	0·36	1·76
Carbonate of Lime and Magnesia	2·62	7·94
Phosphoric Acid	0·48	0·66
Alumina and Oxide of Iron ...	15·42	4·36
Insoluble silicious matter ...	38·51	8·08
Free Lime	—	2·45
	100·00	100·00
Total Nitrogen in the organic matter calculated as Ammonia	0·93	1·06

In 1885 P. F. Frankland made a number of experiments on clarification, more especially with reference to the removal of micro-organisms from water,* trying chalk, animal charcoal, coke, spongy iron, china clay, brick-dust, plaster of Paris, oxide of manganese, etc. He proved that although suspended matter and organisms were at first carried down by the solid substances added, they arose again subsequently, and the organisms, especially those which were motile, multiplied in the liquid.

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* *Proc. Roy. Soc.*, 1885 ; *Proc. Inst. Civ. Engineers*, 1886.

With a similar object, Krüger, in 1889,* tried clay, chalk, infusorial earth, ignited alumina, brick, charcoal, coke, sand, magnesia and wood ashes, confirming previous conclusions.

Therefore, at a time when it was believed that the object to be aimed at was the removal of micro-organisms, it was proved that mechanical clarification was unsatisfactory, as although it would remove the suspended inert solids, the process had little or no influence on the organic matter in solution.

Chemical Clarification or Precipitation.

Lime, since the success of Clark's process for treating waters, has been very widely used for sewage, either alone or as an accompaniment to other precipitants. The Rivers Pollution Commission of 1868 made their first experiments on the precipitation of sewage with milk of lime alone, and pronounced it to be a failure, as, although the liquid was rendered clear, it was not sterilized, was rendered alkaline, ammonia was developed, and the whole rapidly became foul. Where Local Boards have used lime and sedimentation alone before discharge into rivers, a prosecution for nuisance has almost invariably followed. Yet, according to Mr. Mansergh's Report for 1899, the entire sewage of Sheffield, with 350,000 inhabitants, passes to the works by gravitation and is there treated by lime, when, "after a short period of quiescence, the clarified water is run off from the top downwards by floating outlets, and after flowing in a thin layer over flat paved surfaces known as 'aerating weirs,' and through the tank formerly used as a coke filter, it passes into the Don below Jordan weir, 1000 yards down stream. The precipitated matter is swept out of the tanks at least three times daily into the sludge chambers, and pumped therefrom on to open sludge beds, where it remains until it becomes more or less portable by the evaporation and percolation of the moisture. It is then removed by rail and disposed of in the country." The result, as might be expected, is not satisfactory, and bacterial treatment is being considered.

At Birmingham also the lime process has led to legal proceedings, which alleged great pollution of the river Tame. Col. Moore† states that "In some cases $\frac{1}{3}$ grain of chloride of lime (bleaching powder) per gallon has also been added with beneficial results, especially in hot weather, in preventing the growth of fungus. The cost of the process has been found to be about 8d.

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* *Zeits. für Hygiene*, vii., 86.

† *Sanitary Engineering*, 1898, p. 445.

per head of population per annum. The precipitants, however, render the effluent alkaline, and its discharge into rivers favours decomposition, and is very destructive to fish."

Whatever be the cheapness of lime, therefore, it has not been found to be successful *alone*, but as an adjunct to other processes it is frequently of great use, and may be absolutely necessary in some cases where the sewage is strongly acid from trade effluents.

A good quality of lime is slaked, and then ground in a mortar mill or lime mixer with a portion of the sewage or other water to an even cream. The quantity to be added must be regulated by the content of actual free lime. As this varies, it should be determined at intervals by diluting a measured sample (5 cc.) of the *well-mixed* cream with recently boiled distilled water to 250 cc. in a stoppered flask, well agitating, allowing to settle, withdrawing an aliquot portion with a pipette, and testing the alkalinity by standard hydrochloric acid and methyl orange. Some commercial quicklimes contain large quantities of impurities, hence the valuation as to *real* lime is necessary. In all forms it loses strength by absorption of carbonic acid if exposed to air, therefore bins, vats, or tanks for storage require to be carefully covered. The usual dose of lime, when used alone, has been one ton to each million gallons, or 15·68 grains per gallon.

In using lime alone the following conditions must be observed :—

1. Sufficient must be used, in the case of acid or trade effluents, for neutralization and precipitation.

2. In ordinary cases, enough must be added to combine with the free carbonic acid, and half of that combined as bicarbonate as in ordinary water softening ; the precipitated carbonate of lime carries down much organic matter.

3. A slight excess is generally needed to precipitate organic acids and colouring matters of a humous character.

4. Best results are obtained when the lime is in solution ; if only suspended, its action as a chemical precipitant is necessarily diminished, while all the insoluble impurities are added to the sludge.

5. The effluent must not be rendered more than faintly alkaline : this must be ascertained by a determination of the alkalinity of raw sewage and effluent.

6. The amount used will vary according to the quality of the sewage and of the lime.

Dibdin has drawn attention to the solvent action of lime on many of the suspended matters in sewage, so that "the addition of an excessive quantity of lime, while affording a rapid settlement of the sludge, and a more or less clear effluent, dissolves a by no means inconsiderable quantity of the offensive matters previously in suspension, and this is apt to render the last state of the liquid worse than the first. The well-known offensive character of the liquids from sludge-presses when lime has been used is an example of its solvent action."

If other water than sewage is used for making up the lime mixtures, the corresponding dilution of the effluent must be remembered in judging of its quality.

When lime is used in conjunction with salts like sulphates of alumina and iron, there will be no free lime left if the molecular proportions are observed, thus :—

$$Al_2\,(SO_4)_3 + 3\,Ca\,(OH)_2 = Al_2\,(OH)_6 + 3\,Ca\,SO_4.$$

$$Fe\,SO_4 + Ca\,(OH)_2 = Fe\,(OH)_2 + Ca\,SO_4.$$

$$Fe_2\,(SO_4)_3 + 3\,Ca\,(OH)_2 = Fe_2\,(SO_4)_3 + 3\,Ca\,SO_4.$$

Only sulphate of lime will be left in the liquid, increasing its permanent hardness, and affording a measure of the sewage when discharged into rivers.

Alumina or Iron Clarification.—The use of aluminium and iron salts as clarifiers and deodorizers has long been known. It depends on several actions, namely :—

(1). Forming, in neutral solutions, insoluble compounds, called generally "lakes," with coloring matters and other dissolved substances.

(2). Antiseptic power of the metallic salts themselves, and also, in commercial specimens, of the excess of acid, generally sulphuric, with which they are mixed. The latter, when they are used conjointly with lime, or when the acid is neutralized by the ammonia or other alkalies of sewage, will of course not count.

(3). In an alkaline solution, the gelatinous precipitate of hydroxides entangles and carries down suspended matters, including organisms. The latter, however, rapidly rediffuse in the liquid, as in the case of other mechanical agents, so that the precipitate must be quickly separated. This separation, by deposition and filtration, with subsequent sludge-press, adds a great difficulty and expense to the method.

(4). Aluminium and iron salts neutralize ammonia and basic compounds, and the latter destroy sulphuretted hydrogen, the ferrous salts by forming a black sulphide, Fe S, the ferric compounds by oxidizing it to red-brown ferric sulphate, $Fe_2 (SO_4)_3$, forming an ochreous deposit which acts as a further purifier. This red deposit often occurs from iron naturally present, and shows generally that the liquid has been so far oxidized.

Aluminium Sulphate is made from bauxite or clay, by treatment with sulphuric acid. As sold, it often contains excess of the acid, and samples should always be tested, as the more neutral it is the better. Freedom from iron is not requisite for this purpose, in fact "Spence's Aluminoferric" is a mixture of the crude sulphates of iron and alumina, made in blocks which slowly dissolve. The amount of iron present in this compound is, however, small.

Alum, the double sulphate of aluminium and potash, or ammonium, has the advantage of a definite composition, so that an exact quantity can be used, but is precluded by its cost, and also by its leaving behind the alkaline sulphates. In local purifications on the small scale, it has often been of use.

Iron Salts.—Iron is distinguished from aluminium in having two oxides and two classes of salts, *ferrous* or proto-salts, from Fe O, and *ferric* or per-salts from Fe_2O_3. When chemical precipitation was prevalent, there was much controversy as to whether ferrous or ferric salts should be used. The former were cheaper, in the form of ferrous sulphate, or "green copperas," but had the disadvantage of being *reducing*. Copperas with lime was largely used for London sewage. The precipitate of ferrous hydroxide, $Fe (OH)_2$ absorbed oxygen from the air, and to a certain extent communicated it to the organic matter, acting as a carrier.

Ferric Salts not only possess a higher power of clarification, but also act as direct oxidizers. A solution of ferric sulphate has been used in several systems of purification, and the small quantity present in "alumino-ferric" may consequently be advantageous. Ferric chloride, with lime was formerly employed, especially at Northampton. The presence of arsenic in it was commented on by Letheby, Hofmann, and Frankland. "Clarine" was a basic ferric chloride.

An important difference between the behaviour of ferrous and ferric salts as precipitants, is not only that the former act as *reducers*, diminishing the amount of free oxygen available, but that ferrous oxide is soluble in alkaline liquors, while ferric oxide is almost entirely precipitated, so that a liquid treated with ferric, or per-salts of iron, after filtration or deposition may contain no iron, whereas one from ferrous or proto-salts such as copperas, retains iron dissolved in the ferrous state, and on exposure to the air, gradually oxidizes and gives rusty deposits.

In examinations of effluents where iron salts had been used, I have observed that a residue of the metal was always left in solution,—with ferrous salts from the solvent action of alkalies already mentioned : with ferric compounds from the well-known fact that organic matter prevents their precipitation by alkalies. After a time, if not thoroughly aerated, a black deposit of sulphide of iron is liable to form and is often seen on sides of channels. The presence of these salts is also injurious to fish, and hinders nitrification. Aluminium salts have not these disadvantages.

The Massachusetts experiments investigated the effect of different amounts of chemicals in removing micro-organisms from sewage. It was found better to add the metallic salts first, and then an equivalent amount of lime afterwards. Ferric sulphate gave the best results as to removal of organisms and organic matter, copperas or alum acting about equally in the second place. As regards cost, their table gives the preference to copperas (ferrous sulphate), and lime. At the London County Council Works, Mr. Dibdin used 1 grain of copperas and 4 grains of lime to 1 gallon sewage. His experiments as to the effect of various amounts of different precipitants on sewage are given in the table, p. 131.

He concluded that where it is intended to treat the sewage by chemical means, the following rules should, as far as practicable, be observed :—

(1). That the sewage should be diluted as little as possible.

(2). That agitation after mixing should be avoided.

(3). That, unless absolutely necessary, no pumping should take place before precipitation, the reason apparently being that the entanglement of air with the precipitate prevents settling.

He also infers that :—

1. With lime, iron is superior to alumina, and also cheaper.
2. That a large increase in the quantity of chemicals yields no advantage.

At Glasgow, precipitation is effected by adding sulphate of alumina and lime in the proportions of two parts of unslaked lime to one of alumina, the quantity used varying according to nature of the sewage, which is judged of by its colour, the palest sewage having the minimum of five grains of unslaked lime per

LONDON MAIN DRAINAGE.

Percentage Reduction of Oxidisable Organic Matter in Solution by Chemical Precipitation, in grains per gallon (Dibdin).

Liquid used for experiment.	Percentage reduction of dissolved oxidisable organic matter by treatment of liquid with																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Raw sewage from	Lime in solution .. 3.7	Lime in solution .. 5.0	Lime in solution .. 10.0	Lime in solution 15.0	Lime as milk 15.0	Lime in solution .. 3.7 Iron sulphate.. .. 0.3	Lime in solution .. 3.7 Iron sulphate.. .. 1.0	Lime in solution .. 3.7 Iron sulphate.. .. 2.5	Lime in solution .. 3.7 Iron sulphate.. .. 5.0	Lime in solution . 5.0 Iron sulphate.. .. 2.0	Lime in solution .. 5.0 Iron sulphate.. .. 4.0	Lime in solution .. 5.0 Iron sulphate.. .. 5.0	Lime in solution .. 5.0 Iron sulphate.. .. 8.0	Lime in solution .. 5.0 Iron sulphate.. .. 10.0	Lime in solution .. 10.0 Iron sulphate.. .. 10.0	Lime in solution .. 5.0 Alumina sulphate.. 5.0	Lime in solution .. 5.0 Iron sulphate.. .. 5.0 Animal charcoal .. 5.0	Lime in solution .. 5.0 Iron sulphate.. .. 1.0 Alumina sulphate.. 5.0	Lime in solution .. 7.0 Iron sulphate.. .. 1.5 Alumina sulphate.. 5.0	Lime in solution .. 10.0 Iron sulphate.. .. 2.0 Alumina sulphate.. 10.0	Lime in solution .. 14.0 Iron sulphate.. .. 3.0 Alumina sulphate.. 10.0	Lime in solution .. 15.0 Iron sulphate.. .. 3.0 Alumina sulphate.. 15.0	Lime .. .. .. 28.0 Iron sulphate.. .. 6.0 Alumina sulphate.. 20.0	Lime .. .. .. 56.0 Iron sulphate.. .. 12.0 Alumina sulphate.. 40.0	Lime .. .. ..700.0 Iron sulphate.. ..100.0 Alumina sulphate..500.0	Average.
London Main Drainage ..	20	26	29	37	30	27	27	29	33	31	33	35	34	36	36	33	40	32	32	34	37	39	44	49	53	34
,, ,, ,, ..	6	10	28	64	12	10	10	18	32	27	34	32	36	38	36	32	32	33	36	67	46	45	40	43	58	33
,, ,, ,, ..	18	21	14	19	22	12	19	25	24	26	21	27	28	30	28	15	27	19	17	25	22	23	21	28	45	23
,, ,, ,, ..	26	26	26	37	10	24	25	38	33	30	31	32	32	36	30	26	32	30	31	30	25	36	30	30	45	30
,, ,, ,, ..	10	9	10	12	11	10	12	13	27	26	24	24	21	25	24	16	24	14	14	16	12	29	14	26	41	19
,, ,, ,, ..	23	29	29	34	27	23	27	35	37	33	33	39	36	36	40	37	38	38	39	33	37	39	44	55	62	36
,, ,, ,, ..	2	8	15	29	0	0	5	17	20	12	16	22	25	28	32	16	21	19	24	22	11	26	20	24	59	19
,, ,, ,, ..	12	25	30	33	25	16	22	24	32	26	30	34	37	41	32	24	26	28	32	29	25	31	28	43	59	30
,, ,, ,, ..	7	19	21	27	10	18	9	20	22	17	14	25	42	25	26	21	26	19	21	16	19	22	29	31	54	22
,, ,, ,, .	5	12	13	18	4	5	3	11	16	13	15	17	21	22	21	16	22	21	25	25	25	26	25	25	45	18
,, ,, ,, ..	3	12	9	18	3	10	13	15	17	14	13	17	19	21	16	14	15	13	15	16	11	14	8	18	39	15
,, ,, ,, ..	15	16	19	48	44	11	15	17	20	17	21	20	24	25	38	24	24	25	24	26	27	38	40	46	59	27
,, ,, ,,	12	15	21	25	17	10	16	20	22	17	20	22	26	25	24	16	22	25	21	21	24	22	25	40	54	22
,, ,, ,, ..	9	15	19	23	19	11	17	20	21	18	18	19	22	32	19	23	18	19	19	20	18	20	19	18	48	20
,, ,, ,, ..	10	14	22	19	9	8	16	14	14	16	17	21	20	20	21	21	19	16	17	22	27	19	17	21	47	19
,, ,, ,, .	12	12	17	24	12	7	12	12	22	19	19	21	23	23	24	15	19	17	18	22	26	25	28	39	62	21
,, ,, ,, ..	15	16	16	15	9	9	11	13	17	13	14	15	20	11	17	10	19	15	14	15	13	17	16	17	45	16
,, ,, ,, ..	8	8	20	35	8	11	8	14	17	14	20	19	26	27	31	20	23	18	23	28	29	31	30	41	58	23
,, ,, ,, ..	8	7	19	34	7	10	7	13	16	13	19	18	25	26	29	19	22	17	22	26	18	29	29	40	55	20
,, ,, ,, ..	3	4	4	4	9	4	4	4	8	7	6	8	8	10	10	0	7	7	11	12	13	12	13	29	58	10
,, ,, ,, ..	4	5	5	0	7	5	5	7	5	7	7	9	9	7	11	0	12	11	12	13	14	11	13	16	44	10
,, ,, ,, ..	12	20	26	28	16	15	22	23	24	23	22	23	26	22	23	22	20	20	20	22	21	25	22	33	59	23
,, ,, ,, ..	6	9	9	14	3	5	5	7	11	9	12	12	14	13	14	10	10	11	28	18	12	12	14	19	50	17
Average	11	15	19	25	13	11	13	18	21	18	19	18	25	25	30	18	22	20	22	24	21	26	24	31	52	—
Cost per annum for chemicals	£ 13,505	18,250	36,500	54,750	54,750	15,695	20,805	31,755	50,005	32,850	47,450	54,750	76,650	91,250	109,500	82,125	237,250	89,425	100,375	178,850	200,750	268,275	401,500	803,000	9,672,500	—
Sewage from other sources ..	—	52	—	—	—	—	—	—	—	58	61	—	61	69	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, ,, ,, ..	—	—	10	—	—	—	—	—	—	—	—	56	—	—	—	33	—	—	—	—	—	—	—	—	—	—

Lime taken as costing £1 per ton ; Iron £2 per ton ; Alumina £3 10s. per ton.

Volume of sewage taken at 156,800,000 gallons per day.

gallon. When alumino-ferric is employed, a common proportion is 5 grns. per gallon, mixed with 7 grns. of lime.

The "Aelite" precipitant of the "Magnetite" Company is described as a mixture of "alumina, iron salts, and oxidizing compounds," 7 grns. per gallon being used for ordinary domestic sewage, preceded by screening and followed by filtration through magnetic oxide of iron, Fe_3O_4.

"Ferrozone" was also at one time in much use as a precipitant, and was of similar character.

In the application of chemicals to sewage it is necessary to remember that

(1) The real strength of precipitants should be periodically ascertained by analysis.

(2) In view of the varying flow, the easiest plan is to store a large weighed quantity of the reagent, dissolved in a definite volume of water or sewage. The receptacle must be carefully protected, and so arranged that a measured volume can be drawn off as required. The whole process, in fact, must be *quantitative*. Many precipitants take some time to dissolve, and the water used should be in proportion to their solubility.

It is hardly necessary to warn against the occasional careless system of turning in so many hundredweights of crude precipitant into a tank of raw sewage, stirring roughly, and taking no notice of the lumps or debris that remain.

Many devices have been invented, some patented, for regulated supply and proper mixing of chemicals with sewage, some claiming to automatically dissolve and distribute any precipitant in solution according to the increase or decrease in the flow of sewage.* Amongst these, Wolstenholme's, Goddard's, Massey and Warner's, and Reeve's are in use in many places.

For separating the clarified liquid from the precipitate, either siphoning, drawing off from cocks at different levels, or letting out the sludge at the bottom, is applied, with a large number of patented modifications.

An ingenious automatic apparatus (fig. 17) for regulating the supply of chemicals in proportion to the flow of the sewage is described by Mr. Herbert Law.† It is in use at Oldham.

Settling Tanks may be constructed on the intermittent system, in which the liquid is allowed to rest quiescent for a certain number of hours, and the clear portion is then decanted. A

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* For description see Col. Moore's *Sanitary Engineering*, 1898, p. 443.

† *J. San. Inst.* xvii., 476.

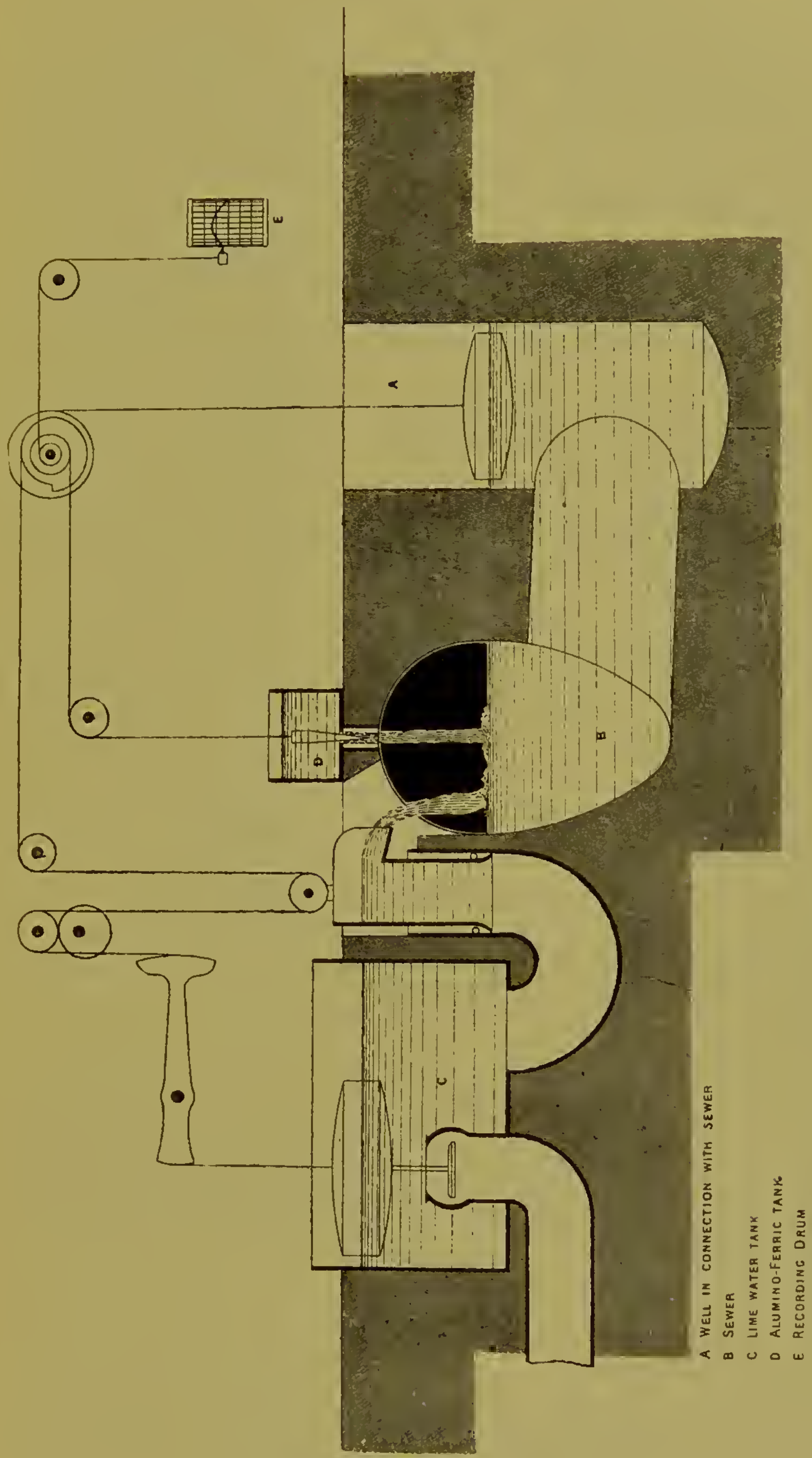
A
B
C
D
E
A Well in connection with sewer
B Sewer
C Lime water tank
D Alumino-Ferric tank
E Recording Drum

Fig. 17. Oldham Apparatus for Mixing Precipitant.

more usual method is *continuous* sedimentation, when the whole runs very slowly through a tank of sufficient depth to allow the solids to gravitate, while the clear solution overflows from the top. Santo Crimp states that the minimum size of the tanks should be such as to hold two hours' sewage flow during the period of maximum discharge, and this quantity may be roughly estimated at one-seventh of the whole day's flow.

In those cases in which chemical precipitation is dispensed with, the rate of settling may necessitate a larger capacity than this, especially if the tank is designed not only to remove suspended matter, but also to bring the organic suspended solids into solution. It will, therefore, be seen that in those cases in which it is proposed to adapt tanks constructed for chemical precipitation to the settling of sewage prior to bacterial treatment their size must be augmented sufficiently to allow time for the solution of the organic solids. Such tanks are originally too large to act as grit chambers, and too small if sludge is to be dissolved.

The relation between occasional flushes and the steady ordinary flow will vary with locality, and has to be specially determined by gauging at intervals (p. 18). A fairly constant average from day to day will be found, with irregular interferences from storms. On the combined system of sewerage, these render necessary the large surplus capacity given in the L.G.B. regulations ; but even on the separate system, when storm water is excluded, they temporarily increase the volume.

Forms of Settling Tanks.—Many forms have been devised. At first they were simply earth or clay-lined reservoirs with flat bottoms, from which the settled liquid was drawn by syphon pipes at a little distance from the bottom, the soakage into the porous sides allowing great foulness. Then iron tanks were constructed, with flat bottoms, and outlet pipes placed generally at too low a level, the removal of the sludge at intervals requiring emptying and drawing off with considerable labour. A further improvement was to make the tank rectangular, four times as long as broad, with its lower surface inclined 1 in 80 to 1 in 100 towards the inlet end. Transverse walls, coming near to the surface, divided the tank, so as to allow the sewage to deposit and flow over them, while " scum plates " dipped from above, and intercepted any floating matters. At the base of the transverse walls there were openings allowing the sludge to gravitate, or be carefully swept down, to a well at the lowest point at the inlet

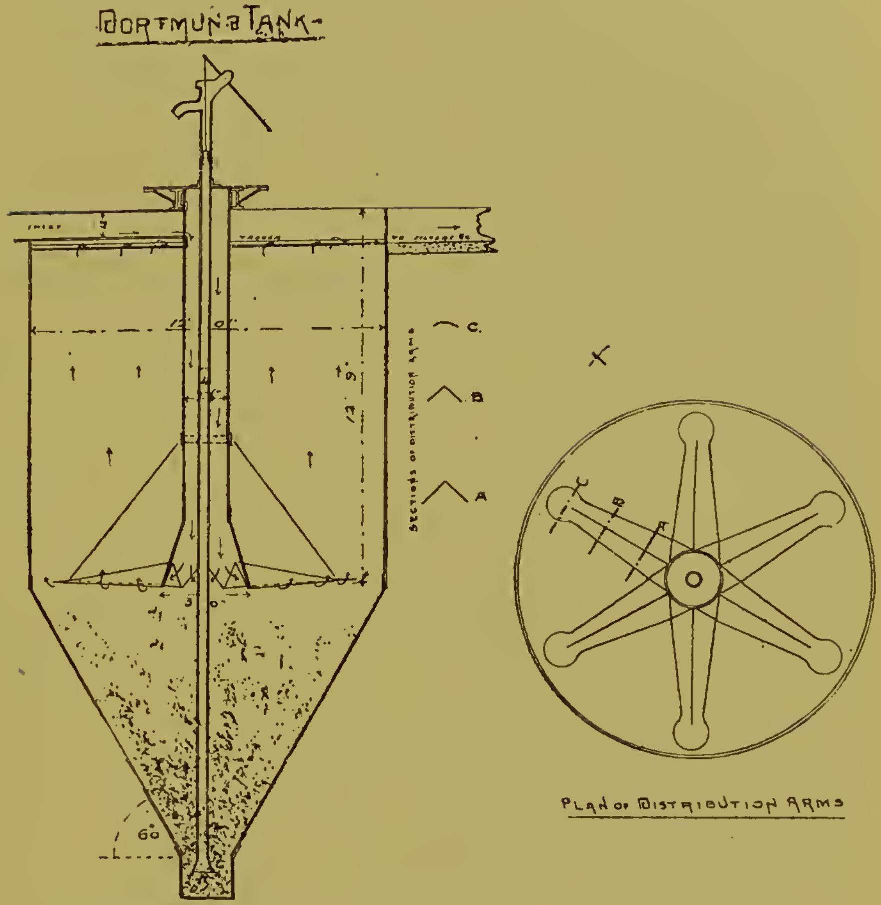
Dortmund Tank
Inlet
Trough
To Filters &c
12' 0"
9'
13'
3' 0"
60°
Sections of distribution arms
C.
B
A
B
A
Plan of Distribution Arms

Fig. 18. Section and Plan of Dortmund Precipitating Tank.

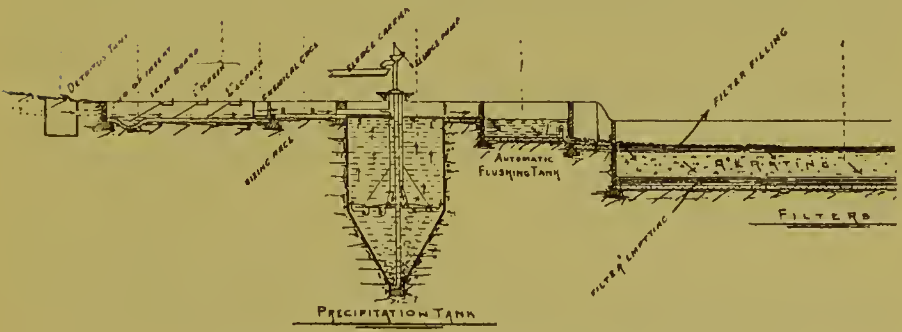
Detritus Tank
Screen
Chemical Cock
Sludge Carrier
Rising Arch
Automatic Flushing Tank
Filter Filling
Aerating
Filter Emptying
Filters
Precipitation Tank

Fig. 19. Plan showing Settling Tank and Dortmund Tank for Precipitating before Filtration.

end. At the upper end, the clarified liquid was drawn by a valve or a floating arm. Santo Crimp gives as examples of the capacity of settling tanks: Coventry, 42 per cent. of the day's flow; Birmingham and Burnley, 56; Leicester, 40; Wimbledon, 80 (designed for a large increase in population).

The Dortmund Tank is circular and deep, with the lower part conical, and with a vertical cylinder fixed in the middle (figs. 18, 19). The strained sewage, after treatment with lime and aluminium sulphate, passes downwards through the central cylinder, and is then distributed horizontally by specially constructed arms. The sludge deposited in the cone is withdrawn by suction pumps through a 6-inch pipe opening near the bottom, at a uniform rate of 15ft. per hour. This tank was first used at Dortmund, in Germany, subsequently at the Chicago Exhibition, and at Alfreton and Ilkeston in England. The deposition in conical vessels has been long known in laboratories as a means of concentrating precipitates. The idea aimed at in the Dortmund is timing the deposition with the withdrawal of clear liquor. The fault of conical, as distinguished from cylindrical vessels, is that the former allow deposition on their sides, the greater in proportion to their low angle. Hence the working is sometimes deficient, "the sides of the cone being coated with filth, which decomposes, making the effluent very unsatisfactory."

At Essen (Rockner-Rothe principle), shallower tanks are adopted with pneumatic raising.

Cosham's Tank has the advantage of compactness, by means of a radial arrangement with two concentric circles, the middle one being divided into two, the outer space into eight compartments, the whole arrangement being conical, so that the inner two divisions are deepest, and the shallower outside ones encircle them. The sewage passes into the centre, and overflows gradually through the other compartments, with deposition in each. Arrangements are made by which the sediment can be withdrawn from the bottom of each chamber, or passed into the centre divisions and siphoned out collectively.* A rectangular form is also included.

The Ives' Tank is also circular and includes arrangements for aeration and, as a preliminary, the centrifugal reducer of coarser solids already mentioned, with a "chemical cage" for regulating the supply of precipitant. The details, including a "flocculent flue," are very elaborate.†

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* For details see Moore's *Sanitary Engineering*, p. 452.

† *Ibid*, p. 453.

The sludge or precipitate left after either subsidence or filtration putrefies very rapidly in warm weather, therefore requires rapid removal from filters or tanks. It was formerly intended to disinfect it at great cost. It is of very varying composition.

Two methods are adopted for separating it from the water which is its main constituent :—

1. Drying in trenches on porous land; afterwards it is generally dug in.
2. Filter pressing.

The pressed sludge from the London sewage at Crossness averages, according to Dibdin's analysis already quoted :

Water	58·06
Organic matter	16·69
Inorganic or ash	25·25
	100·00
Saline Ammonia	0·035
Organic Nitrogen	0·87

The composition of the mineral matter was affected by the treatment with lime and ferrous sulphate, being :

	Per cent.
Calcium Carbonate	7·94
Calcium Hydrate ("free lime")... ...	2·45
Silica (sandy matter)	8.08
Ferric Oxide	0·97
Alumina (from clay)	3·39
Phosphoric acid	0·66
Magnesia	trace.

the total amount of wet sludge being 30 tons per million gallons. At Wimbledon in 1893, 8·2 tons of pressed sludge cake were obtained per million gallons sewage, the average for a number of towns where filter presses are used being 9·28 tons per million gallons.

In pressing sludge, lime is generally added to make the substance more manageable, as much as 2% is often used. The result, as we have indicated, is a dissolving of the organic matters, and an extra foulness of the pressed liquid, besides the additional bulk.

At Ealing, the sludge was mixed with town ashes and burnt in a refuse destructor; at Birmingham, it was mixed with the general refuse and offered as manure.

Although the addition of lime in small quantities as a precipitant tends to inhibit the multiplication of micro-organisms, it must not be forgotten that large quantities of lime, added either to the raw sewage, or mixed with the sludge to assist consolidation, increase the amount of organic matter in the effluent or sludge-press water, so that these liquids, after their alkalinity has been diminished by dilution or absorption of carbonic acid from the air, readily putrefy.

Sludge includes the greater proportion of the organisms of the original sewage, and when fresh may contain, according to Prof. Boyce, 150 millions per cc., but on standing, the number slowly diminishes, reaching 90 millions after 24 hours, and falling to 7 millions in three months.

With regard to sludge cake, the further addition of lime, together with abstraction of water by the presses, renders the mass almost sterile at first, but when exposed to the weather and to dust, a ripening process takes place on the development of bacterial life.

The value of sludge cake, either as a manure or as fuel, obviously depends on the amount of water present.

At Worcester, Massachusetts, chemical precipitation is still adopted after exhaustive experiments by the State Board of Health, and new sludge plant has recently been installed to deal with the suspended matters from the manufacturing sewage. According to Dr. Kinnicutt, the effluent cannot be turned into the watercourse, unless the dry-weather flow of the watercourse is at least ten times that of the sewage.

In the recent enquiry on the Bradford sewage it was shown there that the large quantity of grease, mainly wool-fat, amounting sometimes to 20% of the dry solids, caused great difficulty in treatment and disposal, preventing the squeezing out of more than 25% of water. It was stated that:—

> "The usual percentage of water in the wet sludge of other towns was 90%, the increase from 90 to 98% making a vast difference in the total bulk of the sludge. Thus wet sludge
>
> with 90% water = 9 vols. H_2O to 1 of solids ;
> ,, 95% ,, = 19 ,, ,, 1 ,,
> ,, 98% ,, = 49 ,, ,, 1 ,,
>
> Therefore, 100 tons of sludge with 90% water became 200 tons with 95, and 500 tons with 98%.
>
> "So that the watery character of the sludge caused its volume to be increased 5 times.
>
> "The sludge being so thin and greasy was difficult to press, and after being pressed in the most improved sludge-pressing machinery, left fully 75% of water in the cake."

The following are analyses of air-dried sludges as given by Prof. Robinson.

ANALYSES OF SEWAGE SLUDGE (Air-Dried).

Name of Town...	Aylesbury.	Birmingham.		Bolton.	Bradford.		Coventry.		Leeds.		Leicester.	Windsor.
Process of Precipitation ...	A B C	Lime.		Lime and Charcoal	Lime.		Sulphate of Alumina.		Modified A B C	Hanson's Process.	Lime.	Hille's Process
		1	2									
Date	1879	1879	1879	1879	1876	1879	1877	1879	1876	1876	1879	1877
Water	12·60	12·70	13·16	14·34	8·90	6·92	14·04	10·04	9·56	16·40	11·93	11.76
Organic matter, Carbon, &c....	35·60	19·19	20·04	26·18	33·75	34·53	20·58	23·09	20·82	27·92	22·18	12·06
Phosphoric Acid	2·11	·40	·72	·62	·80	·73	1·56	2·07	·64	·75	1·21	·87
Sulphuric Acid...	2·70	1·45	·35	·61	·64	1·74	1·32	·56	2·15	1·02	·51	·49
Carbonic Acid	—	7·62	8·53	8·30	10·53	13·77	6·64	5·71	8·42	13·11	15·25	22·71
Lime	2·18	11·19	12·74	14·50	16·90	20·27	9·16	6·65	9·68	17·51	20·16	31·09
Magnesia	·18	·90	1·37	1·06	1·66	5·07	·86	·61	5·64	7·67	1·48	1·58
Oxide of Iron	6·20	2·70	3·20	1·98	2·11	2·01	4·14	2·66	4·61	2·32	2·66	1·68
Alumina...	6·75	2·68	2·58	2·97	3·49	3·89	4·13	5·80	7·04	6·30	1·63	2·31
Sand, &c.	33·50	41·13	37·93	29·50	21·80	10·23	37·83	42·00	31·60	7·36	22·30	14·16
	101·22	99·96	100·62	100·06	100·58	99·16	100·26	99·19	100·16	100·36	99·31	98·71
Phosphate of Lime	4·61	·87	1·57	1·35	1·74	1·59	3·40	4·52	1·39	1·64	2·64	1·90
Nitrogen	1·60	·52	·49	·61	·62	·66	·92	1·27	·66	·70	1·08	·52
Equal to Ammonia	1·94	·63	·60	·74	·76	·80	1·11	1.55	·80	·84	1·31	·63
Calculated value per ton ..	33/0	10/9	11/5	13/4	15/1	15/4	20/0	27/2	14/2	17/2	21/7	11/5

Sludge cake can be brought to 50% water by pressing, and to 12% by air-drying. As the value, either as manure or fuel, is inversely proportional to the amount of water present, it follows that in all cases, air-drying should be used before disposal. In the table (p. 139), the monetary value of air-dried sewage sludges is given, while their calorific value is roughly proportional to the organic matter. Since the latter is largely nitrogenous in character, its value as fuel is much lower than that of coal, and of course the remaining water associated with it must be evaporated before any energy is available.

CHAPTER VIII.

STERILIZATION by Heat, Chemicals, and Electricity—Removing Odour—Metallic Salts—Action of Manganates and Permanganates—Reeves' System—Oxynite Process — Chlorine and Hypochlorites — Bleaching Powder — Hermite — Electrozone—Bergé—Ozone—Liernur Process—Destructors for Sludge and Town Refuse.

THE preceding processes dealt with the mechanical separation of the solids by different methods and the production of a clear effluent, getting rid of each as the circumstances best allowed. Chemicals were sometimes employed, but almost solely with a view to clarification. The Rivers Pollution Commission, and a large number of legal actions, led to attempts at "disinfection" of the raw material or its products. Starting from the observation that organic liquids could be kept from change by heating them, or by adding a certain proportion of an antiseptic, it was thought that raw sewage could in the same way be prevented from putrefaction or offensiveness. These processes aimed at removing or hindering the smell, or destroying the bacteria, at a time when all organisms were held to be dangerous, and odour and appearance were often the only things considered. But the futility of the attempt at disinfection on a practical scale may be seen from the fact that one of the most powerful disinfectants, mercuric chloride, to be reliably bactericide, requires to be used in the strength of about 1 in 1000, which would require for a small local sewage of 20,000 gallons, from under 1000 people, 200lbs. per day, at a cost of over £25 daily, or nearly £10,000 per annum. Less energetic agents, although cheaper, would have to be used in greater strength, thus phenol (carbolic acid) is only effective when used in a 5% strength, and therefore would be required at the rate of 10,000lbs. per day, so that the cost would evidently be prohibitive.

Owing to the foul condition of rivers near or within large towns, vigorous attempts were made to disinfect them with chemicals, or to add the latter to the sewage, with the object of removing or neutralizing free ammonia, compound ammonias, and sulphuretted hydrogen, and so rendering it almost inodorous for the time, and of hindering further decomposition of the organic matters. Any acid or acid salt would neutralize the ammonia; many metallic solutions would absorb sulphuretted hydrogen, and also precipitate much of the organic matter, and a clear effluent without much odour and almost colourless would be obtained. But several difficulties occur :—

1. It is a mistake to suppose that the odorous ingredients of sewage are all basic like ammonia, or readily combine with chemical reagents. Acids and many other chemicals, when added to urine, fæces, or vegetable refuse, develop a very unpleasant odour, which may be often noticed in the vicinity of works where organic matters are treated. Substances like indol and skatol, from fæces, are very weak bases, and readily escape with vapour even from acid solutions.

In distilling sewages or contaminated waters for ammonia and albuminoid, the distillate will be found to have a peculiar nauseous, somewhat aromatic odour, which is so constant that in waters it points strongly to sewage admixture. When in considerable quantities, the compound causing this smell collects as a greasy white scum on the top of the distillate. On account of its ready volatility, and its not combining with reagents, it is very difficult to separate, but from large volumes of sewage, I have obtained it as a white neutral crystalline substance. In small quantities, it floats like a grease on the surface of water: from its odour and general occurrence, though in minute amount, it would seem to be an important cause of the residual sewage odour when ammonia etc. have been removed.

The volatile oil giving the chief odour to urine, has also been isolated, it is neutral and does not readily combine; the same would be the case with essential oils from vegetables, hydrocarbons like napthalene from gas tar, etc. Among acid compounds, phenylacetic acid, which I have isolated from effluents, has a strong odour. Ethereal salts, like mercaptan, may also be mentioned among the many substances which render chemical deodorization inefficient.

2. Chemicals, in the quantities that can be applied, do not kill the organisms of putrefaction, and only to a slight extent reduce the organic matters in solution, therefore the effluent soon resumes a condition of turbidity and foulness. Some of them render the liquid acid, others unduly alkaline—both objectionable features. We have already spoken of the increase of the sludge by precipitants; while the difficulty of sterilizing it is well known.

Occasionally expense is a secondary factor in dealing with offensive discharges, as, for example, from hospitals, so that metallic salts are sometimes of service. Among others, those of copper, on account of their combining with sulphur and ammonia, and their marked germicidal properties, have been used. Their easy removal by lime and sand filtration, with subsequent recovery of the copper from the material, induced Kroncke* to adopt cuprous chloride; others, *e.g.* the French authorities in combating the cholera in 1892, used the cheaper cupric sulphate. Mr. Shrapnell Smith, of Liverpool, stated at the Leeds Sanitary Congress, 1897, that he was using salts of copper, and drawing air through the filter beds by fans.

During the Royal Commission on the Metropolitan Discharge† Mr. Dibdin pointed out that it is possible to thoroughly deodorize sewage by permanganate and sulphuric acid (giving ozonized oxygen), either before or after the removal of the suspended matters by precipitation. Sodium manganate, as a cheaper salt, was used in large quantities in a similar way. It was introduced into sewers at different points, and being strongly alkaline, it disengaged ammonia, which was neutralized by acid treatment at the outfall.

The amount of oxygen liberated from manganates and permanganates depends upon the way they are applied. The maximum, when permanganate with sulphuric acid acts on organic matter is 5 atoms, thus :—

$$K_2 Mn_2 O_8 + 3 H_2 SO_4 = K_2 SO_4 + 2 Mn SO_4 + 3 H_2O + 5O.$$

If the acid be insufficient, a brown precipitate of hydrated peroxide falls, and only 3 atoms of oxygen are liberated :—

$$K_2 Mn_2 O_8 + H_2 SO_4 + 3 H_2O = K_2 SO_4 + 2 Mn (OH)_4 + 3O.$$

Manganate spontaneously gives up 1 atom of oxygen with great readiness :—

$$Na_2 Mn O_4 + 3 H_2 O = 2 Na OH + Mn (OH)_4 + O.$$

With a dilute acid, even carbonic, in excess, it yields permanganate and hydrated peroxide :—

$$3 Na_2 Mn O_4 + 2 H_2 SO_4 = Na_2 Mn_2 O_8 + Mn (OH)_4 + 2 Na_2SO_4$$

The permanganate further changing as shown above.

Manganates were employed for the deodorization of the London sewage pending the opening of the outfall precipitation works.

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* *Journ. f. Gasbeleucht*, xxxvi., 513.

† Vol. xi. page 142.

Many attempts have been made to recover the manganese or iron oxides precipitated in the sludge by pressing, heating in closed retorts, utilizing the ammonia and evolved gases, and employing the residual mixture of carbon and metallic oxides as a filtering medium.

The Reeves system also uses manganate of soda and sulphuric acid for sewers. To remove odours from manholes and ventilators Harris Reeves has constructed an earthenware apparatus in which a solution of manganate of soda is constantly prepared and mixed with concentrated sulphuric acid, so that the heat produced generates vapours of permanganic acid which is strongly oxidizing (fig. 20).

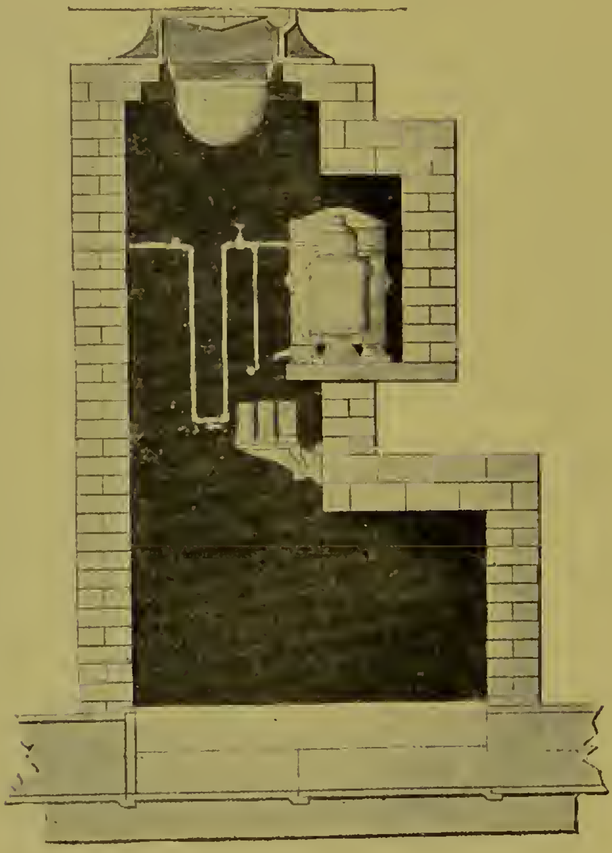

FIG. 20. REEVES' SEWER GAS DISINFECTOR.

A solution of permanganate is used by many vestries in the street watering carts, but it will be noticed that it becomes very rapidly destroyed. An important consideration attached to the use of manganese compounds is that oxides of this metal are invariably left in the sludge. Any metal having two oxides which easily pass one into the other may act as a carrier of oxygen from the air to organic matter. We have spoken of this in connection with iron. Manganese has a still higher range of activity, consequently, the oxygen compounds of manganese have long been used as destructors of organic matter, and a large number of inventions have relation to them. The native mineral pyrolusite, or peroxide, MnO_2, is with difficulty acted on, and almost inert. In the raw state it has been used in filters, or added in very fine powder to sewage ; but beyond mechanical action it gives no oxygen and remains practically unchanged. A better result occurs when it is mixed with carbonaceous matters and heated in closed retorts, so as to reduce it to a lower state of oxidation. On exposure to air and water, a film of flocculent hydrated peroxide is formed, which readily parts with oxygen to organic matter in solution, re-absorbing oxygen from the air when the water has drained away. Such a material has high oxidizing powers, the expense being the main objection.

Bertrand* in his investigation of *oxydases* (p. 85) pointed out the invariable presence of traces of manganese, and suggests that the oxydases are compounds of manganese in which the acid radicle is of a proteid character, and of sufficient activity to keep the metal in solution, whilst the manganese is the real carrier of oxygen. Antoine Villiers† and Achille Livache‡ confirm this view of the agency of very small quantities of manganese in transferring oxygen from one compound to another, and it seems probable that the traces of manganese contained in coke, clinker, and other materials of filter beds may be helpful to oxidizing action by supplying this element to oxidizing enzymes. In *natural* oxidations by traces of iron compounds, such as occur in ferruginous waters, the action of enzymes has also been asserted.

Adeney, in 1894,§ observed that the sludge from sewage that had been treated with manganate of soda slowly evolved carbonic acid and nitrogen gas. This oxidation of the organic matter was attributed by him to the available oxygen of the hydrated peroxide of manganese in the precipitate, as he found that the peroxide became completely converted into manganous carbonate, $MnCO_3$. The process is exactly similar to *denitrification* (p. 98), and is similarly dependent on organisms, as Dr. McWeeney||

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*Comptes Rendus, 1896, cxxiii., 463, and 1897, cxxiv. 1355.

† ibid, 1349. ‡ ibid, 1520. § *Proc. R. Dublin Soc.*, viii., 247

|| *Trans. R. Dublin Soc.*, Aug., 1897.

found that in *sterilized* media the reduction of peroxide to carbonate did not occur. Adeney also showed by thermochemical equations "that if this decomposition of the peroxide of manganese was the result of a fermentation consisting of the direct oxidation of organic carbon at the expense of its available oxygen, the changes would be attended with considerable heat evolution, and would, therefore, constitute a considerable source of energy to the organisms."

Following these researches, but also including the older features of subsidence and chemical precipitation, the "Oxynite" process was put into practice at the Dundrum Asylum, near Dublin; the sewage entering a tank at the bottom, and overflowing above, deposited nearly 90°/₀ of the solid matters "unmixed with precipitating chemicals." In the second tank it was precipitated by manganate of soda and sulphate of alumina; this sludge undergoes the spontaneous oxidation described above, and admits of the recovery of the manganese.* The effluent is mixed with nitrate of soda to supply more oxygen; on this we shall comment later. It will be seen that the larger part of the sludge is not treated.

Chlorine and Chlorine Compounds as conveyors of oxygen have been often used. Chlorine by itself may act in different ways. When concentrated it can combine directly with organic matters or replace the hydrogen in them, precipitating all albuminous substances,† and rendering them imputrescible, besides killing all life. In localised situations, therefore, chlorine and its compounds are effectively used for dealing with special nuisances. The offensive gases of putrefaction are decomposed, sulphuretted hydrogen being resolved into sulphur and hydrochloric acid:—

$$H_2S + Cl_2 = 2HCl + S$$

phosphuretted hydrogen being also decomposed, while ammonia and compound ammonias give ammonium chloride and nitrogen:—

$$8NH_3 + 3Cl_2 = 6NH_4Cl + N_2,$$

hence the copious white fumes frequently noticed when a chlorine mixture is thrown into a dung pit. With more chlorine, intensely acrid vapours which attack the eyes and lungs, due probably to the production of chlorides of nitrogen, are produced. In dealing with cesspools, ashbins, or privies this becomes strongly prominent in chlorine disinfection. Chlorine acts as an oxidizing agent by decomposition of water :—

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* See also Wilson, patent 1725, 1891.

† Rideal and Stewart, *Analyst*, 1897, p. 228.

$$H_2O + Cl_2 = 2HCl + O,$$

the nascent oxygen so liberated being far more energetic than atmospheric oxygen, and acting directly on organic substances. The cheapest source of chlorine is *chloride of lime* or bleaching powder, $CaCl_2O$, which on dissolving in water breaks up into calcium chloride, $CaCl_2$, and calcium hypochlorite $Ca\,(ClO)_2$; the latter only is available for chlorinating or oxidizing. The commercial dry powder contains as a rule about one-third of its weight of active or "available" chlorine.* When mixed with ordinary water containing carbonic acid, the latter decomposes the hypochlorite, setting free hypochlorous acid :—

$$Ca\,(ClO)_2 + CO_2 + H_2O = CaCO_3 + 2HClO.$$

"Chloros" is a solution of sodium hypochlorite $NaClO$, containing 10% of available chlorine.

Allusion has already been made to the use of chloride of lime at Birmingham (p. 126) in small quantity along with slaked lime ; as the latter absorbs the carbonic acid, the action of the hypochlorite is extremely slow.

* The term "available chlorine" means the amount of oxygen that can be liberated by any of the group on reaction with water. Hydrochloric acid and chlorides liberate none. Free chlorine, for every molecule Cl_2, or 71 parts by weight, sets free one atom, weighing 16 parts, of oxygen ; $Cl_2 + H_2O = 2HCl + O$; That is, the weight of chlorine used is about 4½ times the oxygen obtained.

Hypochlorous acid and hypochlorites can break up directly into hydrochloric acid or chlorides and oxygen :—

$$HClO = HCl + O$$
$$Ca\,(ClO)_2 = CaCl_2 + 2O$$
$$Na\,ClO = NaCl + O$$

Hence *pure* hypochlorous acid, or a *pure* hypochlorite, would give one atom of oxygen for one of chlorine, or double the amount yielded by free chlorine. Commercially, however, the hypochlorite is always obtained mixed with an equivalent amount of the inert chloride, as in the formation of solutions of chloride of lime and chlorinated soda :—

$$2\,Na\,OH + Cl_2 = Na\,Cl + Na\,Cl\,O + H_2O.$$
$$2\,Ca\,(OH)_2 + 2Cl_2 = Ca\,Cl_2 + Ca\,(Cl\,O)_2 + 2\,H_2O.$$

Therefore, apart from the question of difference of activity, the "available," or oxygen-releasing chlorine in these chlorinated products bears the same relation to the total chlorine as it does in solutions of the free element. In the manufactured products lime or soda is always present in excess for the sake of stability; but all of them deteriorate when stored, especially in presence of light. The available chlorine requires to be frequently controlled by analyses. In "chloride of lime" it is expected to be 33 to 34 %, in "chloros" solution it is regulated to 10 %.

Hypochlorous acid, like chlorine, can either combine with organic matter directly, forming innocuous compounds, or can break up into hydrochloric acid and nascent oxygen.

Chloride of lime was used before 1884, and again in 1887, for the river Thames during the hot weather, but it was found that "unless large and continuous doses were kept up," the foulness of the stream was not controlled.

Hofmann and Frankland found in 1859 that it required 400lbs. of chloride of lime to deodorize a million gallons of London sewage, the effluent remaining inoffensive for three days.

On the river Brent in 1896, when complaints were made of the effluvium, chloride of lime was scattered on each bank during the warm weather. Its use in dustbins, gulleys, streets, and urinals is well known. Dr. Parkes* has drawn attention to the insanitary condition of wood pavements during a spell of dry weather where horse-droppings are frequent, and recommends that "where the hose cannot be adopted, the wood-paved streets should be watered from carts containing a weak antiseptic and deodorant solution which will inhibit the growth of the putrefactive microbes on the wood surface. Probably the best would be a weak chlorine solution, say 1 part of chlorine in 10,000 to 20,000 parts of water . . . . being volatile it leaves no residue on the road." But free chlorine, even in this dilution, would attack the iron fittings of the carts and the grids of the sewers, and be itself removed as basic ferric chloride. A one per cent. solution of bleaching powder (1 : 300 available chlorine) was used by Sims Woodhead for sterilizing the Maidstone water supply during the 1897 typhoid epidemic.

Although powerful disinfectants, chlorine and the hypochlorites have several disadvantages:

(1). Their own odour, and the persistent odours they create and leave behind, lead often to their use irregularly, or in ineffective quantities.

(2). The action on metals and leather (washers of taps and fittings).—Lead even is corroded, so that in water-closets with leaden syphons, the pipe would be eaten through rapidly. Free chlorine, or acidified chlorine mixtures, exert rapid action on iron, cutting the fittings generally just at the level of the liquid, and even, owing to evolved gas or spray, corroding the metal some distance above. The hypochlorites, being alkaline, are much less destructive, as shown by the fact that iron tanks are largely used to store strong "bleach liquor" in factories.

**British Medical Journal*, December 9th, 1899.

(3). Their immediate destruction by amido-compounds like urea or by ammonium salts, with loss of nitrogen, so that the chlorine may be entirely used up in dealing with inodorous and inoffensive matters, unless a large excess be employed. One reaction between chlorine and ammonia has already been given (p. 146). The complete decomposition would be:—

$$2NH_3 + 3Cl_2 = N_2 + 6HCl.$$

With hypochlorous acid:—

$$2NH_3 + 3HClO = N_2 + 3HCl + 3H_2O.$$

Urea and hypochlorous acid:—

$$CO(NH_2)_2 + 3HClO = N_2 + 3HCl + CO_2$$

Urea and a solution of bleaching powder react thus:—

$$3Ca(ClO)_2 + 2CO(NH_2)_2 = 2N_2 + 2CO_2 + 3CaCl_2 + 4H_2O.$$

Soap and domestic slop waters rapidly exhaust chlorine liquors, while paper, fibre, etc., absorb chlorine readily. Although deodorization, and still more sterilization, can only occur when the agent is in excess; an effluent containing free chlorine, or its oxides, would not be allowed to be discharged into main rivers. Care and certain precautions have, therefore, to be adopted. The presence of excess of chlorine, or its oxides, is tested for by adding a solution of iodide of potassium and starch, which is turned blue.

The soluble hypochlorites are alkaline; when acidified they give off chlorine or hypochlorous acid in vapour, so that the walls of sewers and culverts can be thoroughly disinfected in special cases, as in the drains from hospitals.

On the other hand, the action of unacidified hypochlorites is very slow, especially on organic colouring matters as derived from trade effluents. In the Manchester report of 1898 a portion of the Swinton sewage is thus described:

"*Raw Sewage.*—Pink colour; slight purple suspended matter; *smells of bleach liquor;* neutral to litmus."

"*Tank Effluent.*—Slight pink colour; brown precipitate of ferric hydroxide;"—lime and copperas had been added (see p. 130) —"*smells of bleach;* neutral."

There was an excess of chlorine compounds, since "on the addition of acid, chlorine was liberated equivalent to 0·08 grain per gallon of oxygen" (0·114 parts per 100,000).

The incubator tests given show a slight, but distinct, effect of the chlorine in the bleach.

"Incubator test. Three minutes oxygen absorption."

Grains per gallon.	Before Incubation	After Incubation	Putrescibility.
Raw sewage, high level, as described above	1·90	2·15	Slight after 5 days.
Raw sewage, low level, no bleach...	0·68	1·86	Quite putrid after 4 days.
Tank effluent, as above, from the two mixed	0·88	1·31	Putrid after 4 days.

About 1 in 500 (0.2%) of free chlorine is believed to be necessary to kill organisms.

ELECTROLYTIC PROCESSES.

About 1859, Charles Watt discovered that when a solution of a chloride of the alkalies or alkaline earths was electrolysed, a solution similar to bleaching liquid was formed. It presumably contained chlorides and hypochlorites, but apparently was more active than a solution prepared by passing chlorine into an alkali. Magnesium chloride was said to be preferable.

The Webster process allowed ordinary sewage to flow through channels between iron electrodes, so that the chlorides were electrolysed, the chlorine and oxygen liberated at the positive pole deodorizing the sewage, while the iron salts formed assisted in the purification. Later, aluminium plates were substituted for iron, and the aluminium hydrate generated acted as the precipitant. The danger of these direct processes is that the action may be simply local, a great part of the sewage passing ***between*** the plates nearly or quite unaltered.

M. Hermite electrolyses sea water, and either adds it to sewage, or uses the liquid for flushing latrines and sewers. Dr. Piton's report on the trials at Nice illustrates a point now well established, that an attempt to disinfect hinders or prevents the natural bacteria from breaking down organic débris. He says that "the Hermite solution, diluted to a strength of about 0·25 grm. of chlorine per litre, does sterilize the fæcal matter in the sewers, but that, in spite of the rapid absorption of chlorine, the disintegration of paper and fæcal matter is no more rapid than when ordinary water is employed." The system was tried at Worthing in 1894, and later at Ipswich, and was fully examined by many authorities.*

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* For further details of Chlorine Disinfection see Rideal's *Disinfection and Disinfectants*, 1898, pp. 67-71.

The *Lancet* Commission (1894) found that in the electrolysis of sea water the sodium chloride is not decomposed, only acting as a conductor; but that the magnesium chloride is converted into hypochlorite, which then deposits magnesic hydrate, and leaves free hypochlorous acid in solution:—

$$Mg(ClO)_2 + 2H_2O = Mg(OH)_2 + 2HClO.$$

The Hermite fluid agreed in properties with a solution of hypochlorous acid, made by passing carbonic acid through a bleaching powder solution of the same strength in available chlorine, except that in the bacterial tests the two, for some unexplained reason, were not found to act exactly alike.

The standard strength of Hermite solution was 0·5 gramme of available chlorine per litre. When dilute it rapidly deteriorates.

About 1895, Woolf introduced in America, for water purification, a liquid similar to "Hermite," called "Electrozone," obtained by electrolysing brine containing 2 or 3% NaCl, or sea water. In 1897 a plant was erected for supplying the liquid to the sewage of Maidenhead, England (after previous precipitation with "ferrozone" and filtration through "polarite"), one part being added to from 400 to 600 of effluent. In an examination of the process in 1898, with Professors Robinson and Kanthack, I found that the solution had the properties of sodium hypochlorite, with chloride; the available chlorine being 0·355 %, or practically decinormal, and that although the treated sewage gave at the outfall a blue reaction with potassium iodide and starch, showing excess of the reagent, the amount of organic matter was hardly reduced. On the other hand, the bacterial examinations proved that the germicidal action was very marked, so that "an effluent nearly colourless, free from odour, and containing very few bacteria" was left. I have already alluded to the use of "finishers" in this way.*

The electrozone process has been discontinued at Maidenhead, but it has recently been employed (July, 1899), at Havana, Cuba, for streets, sewage, and harbour; it is stated that it has kept the city practically free from yellow fever, and that the cost of generating is 50 cents per 1,000 gallons.†

When chlorine or its oxy-compounds are to be used, the cost of its production becomes important. It is obvious that the economy of a process will be determined by the quantity of "available chlorine" produced in a continuous process for a given expenditure of electrical energy, or in other words, the cost of electrolytic chlorine per kilo, in comparison with chloride of lime, hypochlorous acid, and free chlorine obtained chemically.*

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* Chapter IV, p. 64.

† *Electricity*, N.Y., Nov. 1st, 1899.

The higher oxides of chlorine have also been occasionally used for disinfection and destruction of organic matter. The expense has militated against their use on a large scale, and is obviously prohibitive for sewages containing ordinary amounts of organic matter.

For oxidized effluents and drinking waters suspected of being contaminated with raw sewage, they, like the hypochlorites, can be used for reducing the number of organisms present and in special cases can produce sterile effluents.

The Bergé process prepares the gas Cl_2O_4 thus:

$$3KClO_3 + 2H_2SO_4 = KClO_4 + 2KHSO_4 + Cl_2O_4$$

The gas is passed into water, and this solution allowed to mix with the polluted effluent. If organic matter is present, it is quickly oxidized by the gas, so that the liquid shows after treatment less organic matter and an increase in the chlorides formed by the reaction of the oxide on the carbonates in solution. The quantity required to produce sterility in drinking waters or effluents practically free from organic matter, by contact for at least fifteen minutes, is given at one gramme of potassium chlorate per cubic metre of water.

B. coli communis and *B. typhosus* in Seine water were killed in three hours contact by ·0024 grms. Cl_2O_4 per litre (·24 part per 100,000) and even when the amount does not exceed ·0008 (or say one part per 100,000) considerable reduction in the number of bacteria is assured. The solution of peroxide used contains about ·13 grm. per litre; it, therefore, is added to the effluent or water to be purified in the proportion of about 1 %.

In Germany, Wiederhold used chlorate and hydrochloric acid during the cholera epidemic. The expense, offensive odours, and danger of explosion, caused their discontinuance.

Many attempts have been made to use *ozone*, either in admixture with air, to be passed through or over the sewage, or to be generated electrolytically in the sewage itself. The latter is a part of the Webster process, the former of Dr. Leed's patent of

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*As to cost of chlorine electrolytic plant, see *Häussermann, Dingler's Polyt. J.*, 1895, 296, p. 189; *Schoop, Zeits. f. Electrochemie*, 1895, ii., [10], 209; *Electrical Review*, 1898, April 29th.

1888 for using electrolytic gases. Hagen (1881) ozonized air by the silent discharge, passed it through sewage, then ozonized it again, absorbing the carbonic acid by lime, so making the process continuous. Marmier and Abraham* have used ozone for sterilizing the water supply at Lille, and state that it removes nitrates and organic matter, and all germs except *B. subtilis*. The cost of the plant is given at £500 for sterilizing 5000 cubic metres per day.

THERMAL METHODS.

To raise the entire volume of sewage to a heat sufficient to sterilize it would be obviously impossible in practice ; in addition, besides the odours evolved, it would leave a liquid which, on fresh inoculation with microbes from air, water, or earth, would become as foul as before.

The Liernur process, as used in many continental towns, is a combination of conservancy, pneumatic removal, and disinfection. The first application on a large scale was granted at Amsterdam, in 1871, where a trial was made on a small quarter of 15,000 inhabitants, but simply for the *conveying* of the fæcal matter and closet water, excluding the household slops. It was also extended to Leyden, Riga, and other places, and afterwards carried out more completely at Trouville in France, where about half of the 1,800 houses are connected up and worked at the company's expense at an average annual charge of 16/- per house. The method is based on the separation of "excrementitious" and "non-excrementitious" matters. The latter, including rain, storm, and surface water and industrial effluents, are conveyed by separate conduits, "utilizing as much as possible the existing sewers of towns." It is said that these liquids "in consideration of their pathogenic inoffensiveness can be safely delivered into the nearest watercourse, after being clarified, if necessary." It must be remarked that as we have shown in the first chapter, road and field drainage is by no means inoffensive, that industrial effluents are frequently putrescent, and that the droppings of animals are often highly pathogenic.

The "polluted liquids, including fæcal matter, sink-slops, soapy and dirty water," pass through 3½in. iron pipes, into closed iron underground receptacles, thence by 4-in. pipes to "district reservoirs," communicating by pipes of 10 to 30-in. internal diameter with the central pumping station. A slight

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*Comptes Rendus, 1899, cxxviii, 1034. *Revue d'Hygiene*, 1899, 321, 540.

vacuum is continually maintained, and at intervals the whole system is exhausted by sections into a main reservoir. In the original description the excreta, with as little admixture of water as possible, were heated with 1 to 2°/₀ sulphuric acid, like a Kjeldahl process on a large scale, until the whole was reduced to a brown syrup, containing nearly all the original nitrogen as ammonium sulphate. This was either distilled with lime and the ammonia utilized, or dried up with ashes and sold as manure, containing, however, usually an excess of acid. The cost in Holland was said to amount to 4s. 10d. per head per annum.

In a report concerning the Trouville installation,* it is stated that the sewage is stored in a large covered brick tank for about a week (thereby undergoing septic change), it is then mixed with "the necessary quantity of sulphuric acid for the purpose of fixing the ammonia," heated in tubular boilers to 120°C, evaporated till semi-solid, and reduced in a rotary chamber to a dry powder which is said to be worth £7 to £8 per ton.

It is admitted that in large towns, evaporation would be impossible; as an alternative, a bacterial treatment is proposed, with sterilization of the sludge by acid and heat and reduction to manure.

TOWN REFUSE.

The solid matters included under the general name of "dust," as removed by carts, have of late years been destroyed by heat in place of the former insanitary methods of shoots, sorting yards, and "made ground," especially since a chance has appeared of utilizing the energy derived from the burning. The older methods of disposal include:—

1. *Carting and tipping on waste land.* Bye-laws in London and other places enact that no land on which refuse has been deposited can be built on until it has remained untouched for at least seven years. Organic matter in such made ground, however, disappears very slowly. Arthur May† stated that some heaps of refuse after one year had contained 30% of organic matter, and after nine years 27%.

2. *Barging from wharves and carrying out to sea.* Much nuisance is occasioned, both at the wharves and along the coast: solid refuse in this respect is much worse than strained sewage.

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* *Report of Surveyor to Tendring Rural District Council*, Essex, July, 1899.

† *Leicester Meeting of Cleansing Superintendents*, 1899.

3. *Sorting with a view to utilization:* now less practised than formerly. According to the above paper:—

> "With regard to street sweepings, of which some two million tons are picked up annually, it is absolutely necessary that each public authority should have a large space available for sorting, sifting, and draining. Some thousands of tons of street sweepings are sent into the country as manure, but the nearest farms are a long way from London, and manuring is done during the season of the year when the amount of street sweepings is the lightest, therefore an allowance of about 2s. per ton has to be made to the farmer to pay the carriage. Even then all tins and glasses have to be sorted out and barged away at a cost of about 4s. a ton. London will produce on a wet day about a hundred times more sloppy street sweepings than on a dry one. This cannot be loaded into railway trucks, but has to be dammed or drained for some long time upon the dépôts, until it is in a fit condition to go away by rail. Then it has to be picked up and carted to the railway sidings, which in itself is no inexpensive matter. The London Vestry, therefore, working under this system, has always a large stock of decomposing vegetable matter on hand, the deleterious effects of which hardly need demonstrating in a densely populated city. Thus we have in many vestry depôts a mass of slop on the one side, and perhaps 40 women screening house refuse on the other, which, in my opinion, cannot be a credit to any sanitary authority."

It is said that the town refuse of Paris is worth £2000 per annum. It is there systematically collected and carefully sorted by "chiffoniers." Sardine and other tins are made into toys and parts of tinware; bottles, rags, etc., are more carefully utilized than in English dustyards, where female labour is usually employed. At Chelsea, for some years, an attempt was made to work up the débris by machine-sorting with graded sieves, using the fine ash for cement, or mixed with the stones, bricks, and clinker as concrete; the breeze and cinders, with the assistance of a little coal, were burnt as fuel for the boilers by which the machines were driven and the works electrically lighted, while a special feature was the manufacture on the spot of a coarse brown paper from the paper and wood fragments. The thermal value of the breeze and ashes sifted out was found to be one-seventh that of coal. The work, however, was discontinued, as the disinfection or sterilization of the various products added considerably to the expense.

4. *Burning.*—Although this is the most perfect means of sterilization, the difficulties have been:—

(*a*) The large and varying proportion of water, which often renders the material incombustible without being dried; the nuisance occasioned during drying in air; and the cost of the fuel for drying artificially.

(*b*) The low combustibility of the material, even after desiccation, requiring assistance by coal, special furnaces, and much labour.

(*c*) The offensive nature of the gases evolved during the burning.

(*d*) The loss of manurial matter as nitrogen and carbonic acid.

(*e*). The low value of the products, ash and clinker, and the expense of their removal.

The accumulations could be greatly reduced, and their character made more tractable, if every householder would follow the advice repeatedly given to burn all his vegetable refuse in the kitchen fire, and throw little besides clean ashes in the dustbin, also by the regulations enforced on the continent and in many places in England, against littering the streets.

In London, over 40 years ago, attempts were made to burn the whole refuse in closed furnaces, but without success, as the means and conditions were not suitable. In 1884, the City of London erected a destructor for burning paper, wood, and the residue of sorting. At most of the yards a simple furnace with a short chimney was employed for the purpose. The combustible refuse, with a little coal, was used for burning the "soft core" (cabbage stalks etc): the result was a smoke, with an intolerable sickening odour, which led to numerous proceedings against these yards. Even where the "breeze" (cinders and small coal) was sold to brickmakers, a serious nuisance was occasioned.

Town refuse may be roughly divided into that derived from *streets*, from *houses*, and from *trades*, the latter, according to the Public Health Act, having to be separately paid for. House refuse is known to be of most miscellaneous character, both in regard to organic and inorganic constituents. Mr. Young, of Edinburgh, states while in London the "fairly combustible matter" in the refuse is 64%, in Edinburgh it is 26%. The average total weight for London in 1895 was stated to be "about one ton per annum for every four inhabitants, or 1¼ million tons for the whole area." The old style of house dustbin was as insanitary as the collection by dustmen was formerly dirty and careless. Many types of portable covered metallic bins, with daily collection, are in use both in London and the provinces.

After the failure to profitably utilize the nitrogenous matters of refuse as manure, its carbonaceous constituents were still available by burning as sources of heat, *after drying*. Modern dust destructors, therefore, dating from 1876, generally include some arrangement for steam raising and electric light, with a view to saving to some extent the cost of destruction. But the aspect with relation to health must always be the first consideration.

The conditions necessary for destructors are :—

1. A temperature not lower than 1300° F. : in good forms 1600° to 1800° is reached, and with forced draught by a steam jet or fans, up to 2000° F. can be in many cases attained by the burning of the refuse itself. The earlier forms, such as the "Fryer," were all of a "low temperature" type, reaching only 750° to 1000° F. in the main flue or combustion chamber. This was not sufficient to deal with the effluvia, therefore Mr. Charles Jones, of Ealing, devised a "fume cremator," erected between the last of the fires and the boiler, through which the whole of the smoke coming from the cells or fires had to pass. In the modern destructor the cremator is not found necessary, since a temperature of at least 1,500° F. can be continuously maintained in the combustion chamber.

2. A supply of sufficient oxygen to maintain steady combustion without over-cooling the gases produced.

3. A suitable site. If this can be central to the district, it will greatly save cost of cartage, etc., and facilitate disposal. Refuse properly cremated, with a high chimney, creates no nuisance, even in populous neighbourhoods.

4. Carriage to the works without offence. Improved covered carts are now constructed. The supply should be as regular as can be managed.

When the temperature of the furnace is not as high as that indicated above, the destruction may be imperfect, and the resulting clinker, instead of being hard, is soft, friable, and sometimes even putrescible ; indeed it is not uncommon for this imperfectly burned clinker to take fire again after being removed. Where used for steam raising, the boilers must be so placed as not to cool down too much the evolved gases.

Street sweepings, which furnish a large portion of the matter to be treated in a dust-destructor, vary very much in composition. In 1892, the sweepings from asphalt pavements in Berlin contained :—

Moisture	38·89
Ash	37·67
Organic Matter	22·44
Total nitrogen	0·479
Ammoniacal nitrogen...	0·004
Phosphoric acid (P_2O_5)	0·452
Potash	0·370
Lime (CaO)	1·891
Magnesia (MgO)	0·347

A sample representing the accumulations for four weeks of the sweepings from a street in Trenton, New Jersey, in 1895, yielded on analysis 0·18 per cent. of nitrogen, 0·3 per cent. of phosphorus pentoxide, and 0·19 per cent. of potash ; this material was valued at 90 cents per ton. The results of analyses of eighteen samples of sweepings obtained from the streets of Washington City ranged between the following extremes :—Organic matter, 35·5 and 10·2 ; nitrogen, 1·18 and 0·17 ; phosphorus pentoxide, 0·16 and 0·1 ; potash. 0·5 and 0·08.

With regard to the fuel-value of dry refuse, authorities agree that it is about one-seventh to one-eighth that of coal. The best conditions, both as to prevention of smoke and fume, and the concentration of heat for utilization, being a slow steady combustion, quick-burning materials do not prove to have any advantage. Thus at the Shoreditch destructor, shavings and fine wood chips, the refuse of cabinet making, were " not as good fuel as the heavy house refuse," while " straw, paper, cardboard, and market refuse were found to be practically of no value as far as steam-raising was concerned."

With a few exceptions, dust destructors consist of massive furnaces or cells with iron fittings, protected by a brick building, and surmounted by a tall chimney. The dust is brought in carts, up an incline, to a tipping platform about 16 or 18 feet above the " clinkering floor " or ground level, and is discharged through feeding holes or hoppers into the upper part of the furnaces, where it meets the hot gases from the lower incandescent portions, and is thereby dried, the average amount of moisture eliminated being 20 to $25^{\circ}/_{\circ}$. It is in this drying part of the process that the main risk of nuisance occurs ; in many old processes it has simply amounted to a distillation in which strongly odorous substances have escaped with the water vapour. Therefore the aim has been (1) to raise the drying gases to as high a temperature as possible ; (2) to subject the evolved vapours to a secondary cremation by passing through ignited material.

Works on engineering must be consulted for details of the various forms of modern dust destructors. The different types have been adapted in different places to local requirements. In Midland towns, where privy middens still exist, their contents have been successfully passed through the destructors along with the ordinary dust.

Colonel Moore states that "with an efficient special furnace about 6 cwts. of ashbin refuse can be burnt per hour with a good natural draught on a fire grate 25ft. square: this may be increased to one ton per hour with a forced draught or air pressure of from 2½ to 3½ inches of water." He gives the cost at from £200 to £500 per cell, according to conditions.

The Horsfall furnace used steam jets to produce a forced draught, with the additional object that the steam, in contact with the incandescent fuel should give, as in the manufacture of water-gas, carbon monoxide, and hydrogen, burning with a very hot flame further up the flue. A feature in this type of destructor is the cast-iron "side boxes," through which the blast air is taken on its way to the grate, keeping the sides of the furnace comparatively cool, and avoiding the destructive adhesion of fused clinker to the brickwork, also at the same time heating the blast. At Geneva, Hamburg, and Monaco the original steam jets were replaced by blowers, which supplied air under a pressure of three inches of water.

The "Decarie" incinerator, Montreal, seems to be much used in Canada and the United States.

The Beaman & Deas destructor has a forced draught, and a second fire-brick chamber where the gases meet a second air supply which completes their combustion. At Leyton, a destructor of this type has been used for dealing with a mixture of two parts of house refuse and one of sewage sludge, in the same way as carried out by Mr. Charles Jones, in 1884, at the Ealing destructor.

The quantity of water in the Leyton pressed sludge amounted to 65%, but the mixture was completely and satisfactorily burnt, yielding about 29% of clinker. The weight of water evaporated per lb. of material burnt was equivalent to 0·426 lbs. per lb. of fuel.

Meldrum's destructor, and Goddard Massey & Warner's form, are also used in several towns and include some distinctive features. At Hereford, a Meldrum destructor is lifting 1½ million gallons of sewage through 33 feet in 10 hours, by the consumption of 8 tons of refuse. Mr. Russell* in reviewing the possibilities of combined refuse destructors and power plants finds, that in the Shoreditch destructor, taken as a type:—

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* *Proc. Inst. Civ. Engineers*, December, 1899.

> "The total amount of refuse destroyed during a period of twelve months was about 26,000 tons, of which 92 per cent. was ordinary domestic refuse, 8 per cent. trade refuse, consisting of straw, paper, etc. The plant consisted of six Babcock-Wilcox water-tube boilers and twelve refuse furnaces of the Manlove-Alliot type, each boiler being placed between two refuse furnaces, the hot gases from which were led into the boiler tubes through short side-flues, each boiler being provided with a special grate, on which coal might be burned if required. The refuse, on arrival at the works, was carefully weighed, and was afterwards shot, without sorting, into trucks, which were raised by electric lifts (of which there were two) to the top platform. On arrival at this point the truck, which was on wheels and fitted with an electric motor, was run off the lift, on the overhead trolley system, to any position where it was desired to empty it; the refuse was then tipped into special charging trucks, one of which was provided for each furnace, and which was operated from the top platform by means of chain gearing. The average amount of refuse received per day was 84 tons, delivered between 9 a.m. and 5 p.m., although as much as 140 tons had been received in one day. It appeared to be impossible in ordinary working to guarantee a regular supply, and it was advisable to provide means of storage to cope with extra large deliveries. This difficulty was met at *Shoreditch* by means of a large rectangular iron storage-bin fixed under the tipping platform, and holding about 60 tons of refuse. The lifts and trucks were operated entirely by electricity. Forced air draught was supplied to the fires by electrically-driven fans, the pressure in the ash-pits being 1in. of water.

The power obtained was used for driving motors and for working the electric-light engines, and deducting the calorific value of the coal occasionally used, Mr. Russell has arrived at the figure of ¾d. per Board of Trade unit generated, as a fair statement of the result. He finds it advisable in practice to assist the refuse furnace by the coal fires whenever the load reaches 250 to 300 kilowatts, although on many occasions a load of 400 kilowatts has been carried by refuse fuel only. The coal is never mixed with the refuse, but is burnt separately on the ordinary grate, under the boiler tubes.

> "The refuse itself burnt freely; the maximum temperature observed being 2500 deg. Fah., and the average 1500 deg. Fah. Considerable inconvenience was experienced owing to cold air rushing into flues during clinkering operations, the trouble being to a great extent unavoidable, calling for a perfect system of dampers. The clinker residue amounted to 32·8 per cent., and was at present difficult to dispose of owing to the cartage from works to

the outskirts of the town being high. It was suitable for making mortar concrete, and, when ground and mixed with Portland cement, made excellent paving slabs. The works were managed on the eight-hour shift system, seven days per week. The feed water for the boilers was drawn cold from storage tanks by three-throw pumps, which forced it through economisers placed in the main flues, where it was raised to a temperature of about 200 deg. Fah. The water was then forced upwards into a large feed-water storage cylinder, 30ft. by 8ft., fixed about 20ft. above the boilers, and was connected direct to the main steam line, and which was therefore at the same temperature and pressure as the boilers, which were fed directly from this cylinder by gravity. The steam generated in the boilers, at an average pressure of 140lb. per square inch, was disposed of mainly by the engines attached to the electric generators, although a small portion of live steam was supplied to the public baths and wash-houses adjoining the electricity works; exhaust steam was also supplied to the baths and free library, which were entirely heated from the steam raised by the refuse destructor.

The average cost of burning the refuse during the second year of working, was 2s. 6·9d. per ton. The amount of electric energy absorbed in dealing with the refuse, including electric fans, lifts, trucks, and lighting, was 4·98 Board of Trade units per ton per annum. Evaporative tests show that with one boiler and two refuse furnaces it was possible, by the burning of ordinary refuse, to evaporate 2888lb. of water per hour, from and at 212 deg. Fah.

The average calorific value was 0·99lb. of water per pound of refuse. The heating surface of each boiler was 1300 square feet; the refuse grate area was 25 square feet, and the coal grate area was 27 square feet. The total amount of energy sold by meter to to consumers was 1,031,348 Board of Trade units, including 131,140 units supplied to the refuse destructor. The total amount of refuse burnt was 26,201 tons, and of coal consumed 1344 tons (value £1308 14s.8d.). The item of cost per ton for interest and redemption of land and plant—not usually considered in connection with refuse destructors—was a matter for serious consideration, and in the case of the Shoreditch destructor plant, where land is very expensive, the charge worked out at practically 1s. per ton."

CHAPTER IX.

BACTERIAL PURIFICATION—History of the Idea and of Early Experiments—Mueller's Process—Mouras' Automatic Scavenger—Massachusetts—London—Sutton—Oswestry—Leeds—Triple Filtration or Contact—Hampton.

A PARTIAL recognition that natural purification of organic matter was due to living organisms was arrived at early in the present century, when Cagniard de la Tour discovered that yeast was a living plant, and Schwamm demonstrated that putrefaction was due to something in the air which heat could destroy and that meat would not putrefy in calcined air. It was suspected therefore, that organisms were the actual cause of decay and putrefactive change, but the powerful advocacy of Liebig and his school of the so-called " Catalytic " theory delayed the general acceptance of the " germ theory " for more than thirty years. " Catalysis " meant that some organic substances, in the act of undergoing decomposition, possessed the power of causing the alteration and decay of other organic substances in contact with them, and this mechanical, as distinct from a biological explanation, held its own until Pasteur proved that fermentation and putrefaction did not take place in the absence of living organisms, which he divided into aerobic, or thriving in presence of oxygen, and anaerobic, or growing without it. Their life history and character have since been elaborated by Koch and a number of other observers. On the other hand, the well-known purifying action of soil, beyond the mere mechanical straining, was, up to a late date, considered to be purely chemical and due to oxidation. E. Frankland, in 1872, had pointed out that " a filter must not be considered as merely a mechanical contrivance, the process carried on being also chemical." This was true, but the necessity of the co-operation of life in the processes was at first almost ignored, more especially as in nitrification, one of the most important of the actions, no accompanying special organism had been discovered. We now know that this was due to the fact that some organisms responsible for nitrous and nitric changes failed to develop in the gelatine or other cultivation media ordinarily used. In 1872, the Berlin

Sewerage Commission reported that sewage matter was converted into nitrates, not by a simply molecular process, but by organisms present in natural sewage and soil. Muntz, Müller, Marie Davy, and others, also demonstrated in various ways how the purification of sewage was accomplished by bacterial action.

In 1881, Hatton investigated* the conditions under which oxygen was absorbed and CO_2 and H produced by bacteria; and also examined the effect of adding nitre to sewage, and concluded that "during the reduction of nitrates by sewage CO_2 is generated in the liquid, and perhaps free N given off while O is absorbed." The experiments were made with a meat extract which had been exposed for some time to the air and was "swarming with bacteria." This is not, however, exactly comparable with the conditions in sewage, where intestinal bacteria and solid matter are present.

Dr. Sorby, in 1883, remarked on the very large proportion of the detritus of fæces which was lost in the river, owing to the action of "countless thousands of living creatures," referring however, to the larger organisms visible under his microscope. Dupré, in a report to the Local Government Board, in 1884, on the results of his experiments on aeration, stated that "the consumption of oxygen from the dissolved air of a natural water is due to the presence of growing organisms, and that in the complete absence of such organisms little or no oxygen would be thus consumed."

Notwithstanding this knowledge, the Royal Commission of 1882-84, after deciding against the discharge of crude sewage into any portion of the Thames, prescribed "some process of deposition or precipitation, the solid matters to be applied to the raising of low-lying ground, or to be burnt, or dug into land, or carried away to sea. The latter course was resorted to as the only one that was thought available for London.

In May, 1886, Dupré "proposed to cultivate the low organisms on a larger scale, and to discharge them with the effluent into the river, as the power these lower organisms had was remarkable"; and at the Sanitary Congress, Bolton, in 1887, he said, "whatever scheme may be adopted, except destruction of the sewage material by fire, the agents to which the ultimate destruction of sewage is due are living organisms, (not necessarily micro-organisms) either vegetable or animal. Our treatment

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Chem. Soc. Journal, May, 1881, "Action of Bacteria on Gases," and "Reduction of Nitrates by Sewage."

should be such as to avoid the killing of these organisms, or even hampering them in their actions, but rather to do everything to favour them in their beneficial work."

Meanwhile, Emich in Germany was experimenting on the changes that occurred in water and sewage on exposure to and after agitation with air, also the behaviour of sterilized water, and the influence of ozone and hydrogen peroxide. His investigations were published in 1885,* and show that

> "When left standing, and after agitation with air, the self-purification only took place if the water had not been sterilized through boiling, and had not been protected against the entrance of germs during the period of observation. If, however, sterilized water was afterwards fully exposed to the air, or if it was afterwards infected with ordinary water, the same changes took place in it as in non-sterilized water exposed to air, viz., the quantity of potassium permanganate required for the oxidation of the organic matter, and the amount of ammonia, decreased with the formation of nitrous and nitric acid. A direct oxidation through the oxygen of the air did not take place; and even one brought about by ozone and hydrogen dioxide plays only an unimportant part compared with that played by the biological process."

All this had main reference to *oxidation*, which, as we have seen in earlier chapters, is only a later part of the cycle of changes through which sewage, and organic effete matter generally, have to pass in the course of purification. The first hydrolytic, or dissolving stage, has been conducted from very early times in a leaky and objectionable way in the old cesspools, which, however, when well managed and under favourable conditions, were quite capable of giving a good result.

The earliest modern initiation of the bacterial treatment of sewage appears, as Mr. Roechling has pointed out,† to be due to Dr. Alexander Mueller,‡ who came to the following conclusions:

> "The contents of sewage are chiefly of organic origin, and in consequence of this, an active process of decomposition takes place in sewage, through which the organic matters are gradually *dissolved* into mineral matters, or, in short, are mineralized, and thus become fit to serve as food for plants. To the superficial observer this process appears to be a chemical self-reduction; in reality, however, it is chiefly a process of digestion, in which the various—mostly microscopically small animal and vegetable organisms utilize the organically fixed power for their life purposes."

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* *Monatshefte*, vi., 77; *Chem. Centralblatt*, 1885, 333.

† *Journal of the Society of Arts*, January 7th, 1898.

‡ *Landwirthschaftliche Versuch-stationen*, xvi., 273.

> "The decomposition of sewage in its various stages is characterized by the appearance of enormous numbers of spirilla, then of vibrios (swarming spores), and, finally, of moulds. At this stage commences the re-formation of organic substance, with the appearance of the chlorophyl-holding protococcus, etc."

It would seem from this, that Dr. Mueller realized the importance of a preliminary change first taking place.

> "Some time afterwards, Mueller took out a patent, in which he endeavoured to utilize the micro-organic life in sewage for the purpose of purification, and which was actually in operation at one time to purify the effluent of some works for the manufacture of sugar from beetroot."

About the same time the "Mouras Automatic Scavenger" was inaugurated in France. According to the *Cosmos les Mondes*, December, 1881; January, 1882; "this mysterious contrivance, which has been used for 20 years, consists of a closed vault with a water seal, which rapidly transforms all the excrementitious matter which it receives into a homogeneous fluid, only slightly turbid, and holding all the solid matters in suspension in the form of scarcely-visible filaments. The vault is self-emptying, and continuous in its working, and the escaping liquid, while it contains all the organic and inorganic elements of the fæces, is almost devoid of smell, and can be received into watering carts for horticultural purposes, or may pass away into the sewer for use in irrigation." As to the theory of the action, it is said, "May not the unseen agents be those vibrions or anærobies which, according to Pasteur, are destroyed by hydrogen, and only manifest their activity in vessels from which air is excluded?"

Observations with a glass model showed that "Fæcal matters introduced on August 29th were entirely dissolved on September 16th, while even kitchen refuse, onion peelings, etc., which at first floated on the surface, descended after a time and awaited decomposition. Everything capable of being dissolved acted in a similar way, and even paper wholly disappeared."

"The principle on which M. Mouras bases the action of his machine are that the animal dejecta contain within themselves all the principles of fermentation or of dissolution necessary and sufficient to liquefy them, and to render them useful in their return to the soil, and without appreciable loss."

A later article of January, 1883, by the Abbé Moigno gives formulæ for the dimensions of the tank, estimating its superficial area as preferably 1-10th metre, or about 1 square foot per person. The Exeter tank, I may remark in passing, works out to about 0·6 square foot per person. The article also specifies that "for the complete solution of the floating solid matter a period of 30 days should be allowed," and it will be seen that this gives :—

$$\frac{1+2+3+\dots\dots+30}{30}M$$

as the total average amount of suspended matter present in the tank at any instant when M is the weight of suspended organic matter present in the volume of sewage dealt with per day. The size of the tank required is, therefore, not so large as to be impossible with ordinary sewages, but the fact that the effluent from such a tank was not sufficiently purified without further nitrification prevented the "Automatic Scavenger" from being more generally adopted.

At the time of the Royal Commission on Metropolitan Sewage Disposal, owing to the failure of most sewage farms to yield satisfactory results, precipitation and attempted disinfection or sterilization, as described in the preceding chapters, were elaborately carried out. In January, 1887, Mr. Dibdin, in a paper on Sewage Precipitation, at the Institution of Civil Engineers, observed that

> "One object claimed for the use of an excessive quantity of lime, and also for some other substances, is that they destroy the living organized bodies, such as bacteria, etc., which give rise to the phenomena known as putrefaction. . . . As the very essence of sewage purification is the ultimate destruction, or resolution into other combinations, of the undesirable matters, it is evident that an antiseptic process is the very reverse of the object to be aimed at."
>
> He also remarked that "very alkaline effluents, such as those produced by the use of lime in excessive quantities are very liable to putrefy, instead of becoming purified by oxidizing organisms."

Meanwhile, bacteriology had been advanced by a large number of researches in various countries, at first directed mainly to the special organisms of disease, but gradually developing a knowledge of the larger class that are not pathogenic, but effect ordinary changes in organic matter.

In November, 1887, the Massachusetts State Board of Health commenced their well-known experiments on the purification of water and sewage by chemical precipitation, and by filter beds. The two first volumes of their reports, extending to 1890, are of classical interest as laying the foundation of the modern developments of bacterial processes. After summarizing the results previously obtained in Europe, details are worked out of different filtering media, size of grains, thickness of strata, influence of time, temperature, and methods of procedure, the results of about 4,000 analyses of raw sewages and effluents being tabulated. At first they aimed at the removal or destruction of bacteria by straining and chemical means without practical success; later they studied intermittent filtration with the actual *assistance* of aerobic organisms. The effects of dilution with the city water were also examined, and naturally, in an aerobic process, the main reliance was on nitrification.

Though on rather too limited a scale to be exactly comparable with practice, the general deductions have been amply confirmed by the success of larger sewage works on biological principles both in Europe and America.

It soon became evident that if a filter bed were worked continuously, it rapidly choked, and putrefaction occurred in the interior owing to a deficiency of aeration, so that on the aerobic plan it was necessary to work intermittently, draining out the liquid, and allowing the entrance of air during regular intervals of rest.

Otherwise it was necessary to have " very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact," a condition, however, which did not prevent the sand filters from becoming over-burdened and also greatly limited the amount of sewage treated. Moreover, the " thin film " oxidation of Massachusetts requires large filtering areas with great labour to keep them in order—therefore, is exceedingly costly when applied to sewage—it is also attended with certain dangers from "channeling " of the beds by careless or too rapid working, or by frost, whereby it arises that the effluent escapes almost unpurified. In the Massachusetts Report of 1890, the process is compared to a combustion, and was found to be most rapid in the summer months. The same Report gives useful information on the methods of analysis, besides observations of the number of bacteria and algæ, and valuable description of the species found in the effluents. It must be remembered that sewage in America is usually weaker and of greater volume than it is in Europe, on account of the more abundant supply of water.*

The sewage of Lawrence City, in the Massachusetts investigation, had been run on the filters without any previous purification, or even settlement. On the other hand, the sewage of London had undergone a previous preparation, by being treated with one grain per gallon of ferrous sulphate and 4 grains of lime, the precipitated sludge being then conveyed in boats to be discharged at the mouth of the Thames. It was hoped that the clarified liquid, after the precipitation, could be discharged into the river direct without creating nuisance. But it still contained about 10 parts per 1,000, or 7 grains per gallon of suspended solids, and was by no means free from odour. The Royal Commissioners of 1884 had decided that the liquid could not be discharged at the outfalls as a *permanent* measure, and required further purification by application to land.

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* The daily consumption of water per head in New York is 92 U.S. gallons; in New Jersey, 92 gallons; in Philadelphia, 143; in Los Angeles, California, 200; in Alleghany, Pennsylvania, as much as 247 gallons. (10 U.S. gallons = 7 imperial). *Mason.*

In 1866 an experiment with London sewage as applied to land had already been made at Barking. The Metropolis Sewage Company obtained a concession to treat the sewage of North London, amounting to about 2,000 tons in nine or ten hours, on five or six acres of grass land on a light gravelly soil. The experiment was not a success, either culturally or with regard to the cleansing of the effluent. But when we come to the 200,000,000 gallons daily of London sewage, it will be obvious that the requisite area of suitable land is entirely unattainable. This being recognised, and an extension of chemical treatment and precipitation having proved to be inadequate as well as costly, the Main Drainage Committee of the County Council in 1891 authorized a series of experiments at Barking outfall, on the lines of the Massachusetts researches. From preliminary trials with small filters, coke-breeze appeared the most suitable material, although burnt ballast nearly equalled it in purifying efficiency. Sand and gravel effected a greater *clarification*, but the removal of dissolved organic matter, as measured by the reduction in the oxygen consumed, given in Mr. Dibdin's report, was considerably less than with the coarser materials, while there seemed a tendency for this effluent to become putrid, owing to deficient aeration from the closeness of texture, and the filter required frequent scraping and renewals. The average rate of working, including periods of rest, was 411,000 gallons per acre, or 250 gallons per square yard in 24 hours. For eight hours a day the effluent ran continuously, the filters being kept full; the filter was then emptied, and allowed to rest for 16 hours.

The figures given by Dibdin, who conducted the experiments, are as follows:—

Clarification, as measured by the units of depth required to obscure a standard mark: Burnt ballast, 1; coke breeze, 1; pea ballast, 1¾; sand 2¼.

Reduction of Organic Matter (oxygen consumed): Burnt ballast, 43·3 per cent.; sand, 46·6; pea ballast, 52·3; coke breeze, 62·2.

The report adds significantly "the number of organisms in the tank effluent before filtration, and in the filtrates, was found to vary very considerably, *those in the filtrate being generally present in larger numbers;* but it soon became apparent . . . . . . that the presence of a large number of organisms was evidence of the activity of the process of splitting up the organic compounds in the sewage matters passing through the filters. Here it is clear that the main purification was bacterial, and only the beginning of a further resolving change to be carried on in the river. It would undoubtedly have been an advantage if the biological process so initiated could have been allowed to develop a further stage in the filter, but the prescribed object of the experiments was "the attainment of the highest rate of speed consistent with such purification as would remove the obvious objectionable characters such as odour, colour, and liability to putrefaction."

The further experiments with a one-acre coke breeze filter at Barking are well known. As at Massachusetts, it was found that continuous running resulted in clogging and a foul effluent, and that to obtain the best results the commencement must be made with small quantities of liquid, the filter, which was composed of 3 feet of coke breeze and 3 inches of gravel, being at first merely filled and emptied twice a day, with a view to producing an active bacterial bed. Daily determinations were made, from which the following averages are computed:—

Average Analyses from One-Acre Filter (Dibdin).

Parts per 100,000.

Date.	Volume per acre per day.	Oxygen absorbed in 4 hours		Albuminoid ammonia.		Nitrogen as Nitrates.		Per cent. purification by oxygen absorbed.
	Gallons.	Effluent	Filtrate	Effluent	Filtrate	Effluent	Filtrate	
April 7th to June 9th, 1894	500,000	5·85	1·23	·593	·138	·182	·340	79·3
Aug. 3rd to Nov. 9th, 1894	600,000	5·18	1·42	·565	·158	·032	·200	79·6
Nov., 1894 to March, 1895	1,000,000	5 87	1·33	·545	·160	·565	1·00	77·5
April 8th to April 20th, 1895	1,000,000	5·00	1·26	·514	·146	·204	1·10	75·4
May to Sept., 1895	1,000,000	6 62	0·91	—	—	—	—	80·7

The highest efficiency reached was 83 per cent. purification, with a million gallons daily and a shorter time of rest. The filter was finally worked on the system considered to be the best at Barking, Exeter, and Sutton, namely, alternate filling, resting full, and emptying, with a periodical entire rest empty for complete aeration. At Barking, the filling occupied two hours, the standing full one hour, the emptying five hours, so that three cycles of eight hours were completed each day. From 10 p.m. on Saturday, till 6 a.m. on Monday, the filter rested empty, making a period of 32 hours each week. This weekly rest involves the storage of the crude effluent in reservoirs for the corresponding period—a practice which has many objections. At Exeter, where the flow through the septic tank is continuous, and no reservoirs are employed, the cycles are continued, by means of the automatic gear, throughout the entire week, but if a filter shows signs of exhaustion, which occur at long intervals, or rarely through accident, it is thrown out of use for one or two weeks till recuperated.

The one-acre filter is still in use. It is reported that after five years' working it is free from clogging, and its working capacity is not impaired.

It will be noticed that the filtering material is only 3 feet deep, and that it is used for treating an effluent from precipitation by lime and copperas. In 1897-8 new coke beds were constructed at the Northern and Southern outfalls for dealing with raw *screened* sewage, and were made of greater depths, 6, 9, 4, 6, and 13 feet.

In a report of the London County Council giving the results of the working of these beds up to August 9th, 1898, Dr. Clowes and Dr. Houston show that they have been continuing the experiments on the lines of Mr. Dibdin, with special reference to the following points:

"(*a*) The effect of using the coke in fragments about the size of a walnut.

(*b*) The effects of increasing the depth of the layer of coke beyond the usual limit.

(*c*) The extent to which the raw sewage underwent purification by the treatment.

(*d*) The practicability of maintaining the constant" (meaning, clearly, regular intermittent, not continuous) "passage of raw sewage through the same coke-bed, without deterioration, either in the bed or in the effluent.

(*e*) The amount of sewage which could be treated daily by a superficial unit of the coke-bed.

(*f*) The extent to which the effluent underwent further improvment by its passage through a second similar coke-bed.

(*g*) The suitability of the effluent for maintaining the life of fish.

(*h*) The effect of the treatment on the number and nature of the bacteria which were present in the raw sewage."

The report shows that the size of coke is of importance :—

> "The use of ordinary gas coke, in pieces about the size of walnuts, seems to be attended with the following advantages, *as compared with the use of smaller coke.* The larger coke enables the bed to hold a larger volume of sewage. The beds now in use had an original capacity for sewage which was nearly equal to the volume of the coke which they contained, in place of only 20 or 30 per cent. of that volume, as is shown by beds containing smaller coke. The use of the larger coke also allows the bed to be more rapidly filled and emptied, and to be more completely emptied and aërated."

The increase of depth of the beds beyond 5ft. as I had predicted in my Cantor lectures, has not been attended by higher efficiency. The report states that " coke beds similar in character, but differing in depth, have been found to give practically identical purifying effects . . . . . with a 4ft. and a 6ft. bed. A bed 13ft. in depth . . . . has given a purification approximately equal to that effected by the 4ft. bed." The depth is always of great importance both as to fall, volume, and cost. In the intermittent system, the bed is really used at intervals as a storage tank, so that, in this sense, greater depth means higher capacity.

An important point is that the capacity of the 4ft. bed had, during 10 months, been reduced from 50 to 33% of the whole volume of the bed, " mainly due to fragments of straw and chaff, apparently derived from horse-dung, and to woody fibre, derived from the wear of wood pavements. . . . . The original capacity is not restored in any degree by prolonged aeration, which proves that the deposit on the coke surface was not organic matter of animal origin, but it has been found that the vegetable tissue, which seems to be the main cause of the difference in capacity, can be in great measure separated from the raw sewage by a brief period of sedimentation before the sewage is allowed to flow into the coke bed."* It should be noted that it is earlier stated in the report that " the sewage had been *roughly screened* before reaching the coke beds, and was free from larger matter usually described as 'filth,' and from coarse sand and heavy mineral road-detritus . . . ." so that as I have always insisted, the additional sedimentation would mean a further evasion of *complete* bacterial treatment, and a production of a further amount of supplementary sludge.

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* Compare Waring's and Lowcock's Experiments.

A strong confirmation of the suggested origin of the loss of capacity is found in the remark that "the ash in the coke has been reduced in amount by about 25% during its exposure to sewage in the coke-bed,"—cellulose being nearly ashless.

These results confirm the view which has been frequently urged, namely, that these non-animal substances cannot be successfully destroyed without anaerobic action (see Chapter V.), by which they are dissolved with production of gas. They are the great difficulty in all processes where the first or hydrolytic change is not properly specialized. The degree to which the nitrogenous matter is dealt with cannot be traced from the report, as only the "oxygen absorbed" figures are given, and it is obvious that if the non-nitrogenous matter is arrested by the filter bed, the improvement in the effluent as measured by the oxygen-consumed figure must in part be attributed to this cause, at the expense of clogging, or diminution of capacity.

I have already remarked that the first stage requires *no* oxygen, and is actually hindered by it, the second requires some, while the third demands a very large and rapid supply. In place of providing three separate areas in which these conditions are carefully and continuously observed, as we should in the culture of plants which required different amounts of water, heat, or manures, it is attempted to alternate them in *two* receptacles by causing the air in each to be cut off and supplied intermittently, and the sewage to be either stagnant, or run in and out with a rush, with the result that the bacteria are periodically disturbed, and neither class of organisms can work under their normal vital conditions. My own analyses and those of others have proved that under the intermittent system, first adopted from the laboratory experiments of Sir E. Frankland in 1870, the effluents, although the *average* results show a great improvement, yet manifest such fluctuations in character, tending to be periodic, as show that the quiet and regular working of the bacteria suffers avoidable interruption and interference. A small significant fact is that the discharge from the fine beds at Sutton and Exeter, and I believe in other places, is always, at the first rush, turbid and of inferior quality, as a consequence of disturbance. Dr. Clowes also in the above report remarks on the occasional turbidity of the effluent, "apparently due in ordinary flow mainly to the presence of bacteria."

The want of provision of a separate area for the first stage is often concealed by the fact that where the sewers are old, or of great capacity or length, or when the sewage has been stored for sedimentation, the first, or even a part of the second stage may have actually been passed through before arrival at the works, so that the liquid may be quite amenable to the third stage of strong aeration, such as is supplied by Lowcock's, Waring's and Ducat's systems.

A few other points of the London County Council Report remain to be noticed. The description and working of the filter beds will be described in connection with filtering materials. As to the effect of the effluent on fish :—

"Fish die at once when they are placed in the present effluent produced by chemical precipitation, probably because there is a serious deficiency of dissolved oxygen in the liquid. . . . ."* Various fish "have lived for months in the first effluent from the coke beds, and would apparently live and thrive in this liquid for an indefinite period."

In a supplementary report by Drs. Clowes and Houston, (October 26th, 1899), the former finds that the cellulose deposit on the coke containing "some fine coke particles and sand grains, cotton and woollen fibres, and diatoms, but consisting largely of chaff, straw, and woody fibre," caused a diminution of capacity of about one per cent. per week in the 13ft. bed, but that this was reduced to 0·64°/₀ per week by previously sedimenting the sewage in a partitioned wooden trough. The sediment was inoffensive and contained 52 to 70°/₀ of combustible matter. Dr. Houston found 1,800,000 bacteria per gramme of deposit, not accounting, however, for its amount, as "this number of typhoid bacilli, for example, weigh only ·0000147 grm." The character of the bacteria differ somewhat from those in crude sewage. There were more *B. enteritidis* and fewer *coli.* Proteus-like germs were abundant, with *B. prodigiosus*, *arborescens*, and an allied form. From colour tests and inoculations he concluded the probable presence of tubercle bacilli; in only one case however, was a fatal effect produced on animals.

Following the success of the Barking experiments, an installation on the same principle was started at Sutton, Surrey, at the beginning of 1894. The filters were of different materials, but again showed coke breeze to be the best, with burnt ballast as a good second, the latter being very simply constructed by digging out the clay to form a pit about 3 feet deep, and filling it up with the same clay after burning, the cost of a filter of this kind, having an area of rather more than one-tenth of an acre being given as less than £100, including all charges. It will be remembered that the cost of the Barking one-acre coke-filter was stated as £2,000.

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* See Chapter VII., p. 130.

Up to this time the filters had been fed with an "effluent;" that is, a sewage prepared by straining, partial chemical precipitation with lime and ferrous sulphate, and sedimentation.

At Sutton, in November, 1896, chemical precipitation was definitely abandoned, but an important feature of mechanical aid was still retained, since the raw sewage was "screened from grosser solids" by a revolving wire drum already described (p. 120). From two to three tons of solid matter per million gallons of sewage thus escape bacterial action.*

From the screen the liquid passes on to the top of pits filled with coarse burnt ballast called variously "bacteria tanks" or "coarse filters," analogous to the "roughing filters" of former systems, but differing from them in the intention not only to remove solid matter, but to alter it bacterially. The effluent, now greatly improved, is distributed by channels over fine beds of coke-breeze, whence it issues at intervals as a liquid usually clear and deprived of offensive character.

After three months' working, Mr. Dibdin was able to give a satisfactory report. The oxygen consumed by the organic matter was reduced by the tank 66 per cent., and by the filter beds 86·5 per cent. The solids in suspension were reduced by the tank 95 per cent., and by the filter 99·6 per cent., while the filtrate was practically clear, had no objectionable odour, and did not putrefy on keeping. The process has continued to the present time with satisfactory results, except when the filters were overtaxed, "some of them," as Mr. Dibdin reports, "having been purposely worked up to a rate of nearly three million gallons per acre per day, with the result that the bacterial action was evidently checked, as shown by the decrease in the production of nitrates, and an increase in the quantity of organic constituents in the effluent. As the result of careful watching, however, no permanent harm was done, as the filters were immediately restored to their usual condition, when they proceeded to give good results."

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* Thudichum, Soc. of Engineers, Dec. 5th, 1898.

Here again we gather that when there is reliance on presumably aerobic filters and organisms for combined liquefaction and nitration, indiscriminately, in the same receptacles, the result is apt to be variable, and to depend on "careful watching," an inference that is borne out by Mr. Dibdin's figures as given in his later report of analyses during 1896 and 1897.

The average results in his table I have calculated, for the purpose of comparison, to a uniform chlorine content of 12.84 parts, which is the average given for the Sutton crude sewage.

SUTTON SYSTEM (PARTS PER 100,000).

	Cl.	Oxygen absorbed in four hours.	N as nitrites.	N as nitrates.	Free NH$_3$.	Albumind. NH$_3$.	Suspended matter.	Residue on micro-filter millimetres per litre.
Crude sewage...	12·8	6·49	·021	None	12·53	1·13	85·76	3000
Tank effluent...	12·8	3·06	·301	·751	3·85	0·60	5·1	213
Filtrate from coke breeze	12·8	1·19	·087	1·99	1·25	0·316	1·35	23

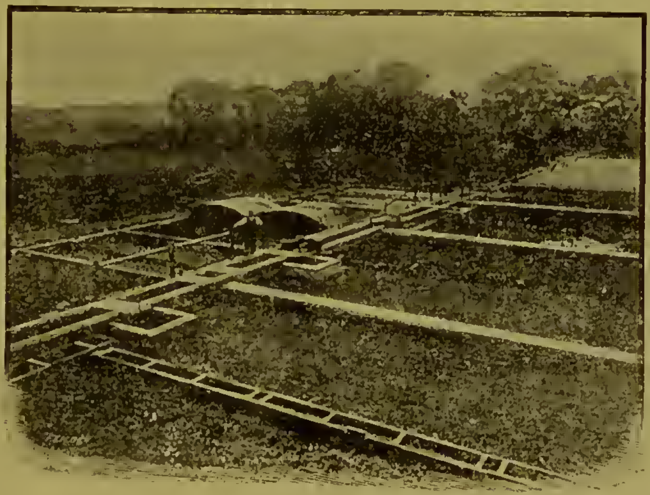

FIG 21. —CONTACT, OR "DIBDIN" FILTERS ON DUAL SYSTEM AT SUTTON.

These figures show the following percentages of purification :

	Oxygen absorbed.	Free NH$_3$.	Albuminoid NH$_3$.	Suspended matter.
By the "bacterial tank"	53	69	47	94
By the coke filter	29	21	25	4·4
Total purification... ...	82	90	72	98·4

It will be observed that the chief purification occurs in the bacterial tank, and that a large proportion of it consists in the removal of the suspended solids.

During the two hours of resting full, a mixture of organisms, of which I believe a great proportion are anaerobic, as indicated by the large production of nitrites, are liquefying the sludge. It was estimated that in the three tanks 80 tons of dry matter had been thus reduced from November, 1896, to December, 1897. During the period of resting empty, the aerobic bacteria are supposed to be at work, although, according to Mr. Dibdin, no air enters except that drawn in while emptying out the liquid. The subsequent coke breeze filter is intended, under the same conditions, to be entirely aerobic and nitrifying. Here also the presence of nitrites may be remarked.

It will be noticed, further, that the Sutton sewage has already been broken down to a very considerable extent, as shown by the 12·53 parts of free ammonia, and only 1.13 parts of albuminoid.

The following further details of the Sutton works are abstracted from reports of Mr. Chambers Smith, the Surveyor :—

> Area of the Urban Sanitary District, 1835 acres ; estimated population in 1899, 16,500 ; inhabited houses, 2,687. The separate system prevails, the storm-water being conveyed in distinct channels, while the sewage is delivered to the farms by two main outfall sewers ; the high level 21in. diameter, and the low level 15in. The works were constructed in 1891-3 for chemical precipitation and broad irrigation. They cover 28 acres, only 18 of which, however, are capable of irrigation.
>
> The average daily flow delivered to the works is 500,000 gallons, 120,000 gallons from the low level having to be raised by two of Atkinson's Cycle Gas Engines of eight nominal horse-power each, and two pumps of the piston and plunger type, 15in. diam. and 15in. stroke, each capable of raising 20,000 gallons per hour through a 7in. rising main 660ft. in length, with a vertical lift of 33ft., while running at a speed of 33 revolutions per minute.
>
> Up to November, 1896, the whole sewage was precipitated by means of 9 grns. of lime and 2 grns. of copperas per gallon of sewage, and the settled liquid passed on to land. The soil, London clay, acting unsatisfactorily, in 1895-6, on the advice of Mr. Dibdin, two "fine-grain bacteria filters" were constructed for the treatment of the precipitated effluent. The sludge from the precipitation was pressed into cake at a cost of £7 per week, but there was no demand for the product, and "the nuisance which is inseparably connected with the process was highly offensive."

In November, 1896, the Sutton Council, on Mr. Dibdin's suggestion, constructed bacteria beds for the treatment of crude (screened) sewage. One of the chemical precipitation tanks was filled with burnt clay ballast, 3ft.6in. deep, the bottom having a 6in. main drain with a screw-down outlet valve, and 3in. branch drains 6ft. apart. The bed "is charged to within six inches from the surface, and the sewage remains in contact for a period of two hours, after which the outlet valve is opened and the filtrate is drawn off, to be further purified on fine-grain bacteria beds, after which the effluent is in a fit condition to be discharged into the brook, and is uniformly superior to the effluent obtainable by land treatment. The coarse grain filters are charged three times per day, an interval of rest of not less than two hours being given each filter after its being emptied. The sludge is absorbed by bacterial agency in the beds, and does not accumulate or manifest itself. No. 1 bed has continued at work with short intervals of rest (about one week in six) almost daily, without a renewal of the filtering material. The beds are, moreover, free from any offensive odour. The automatic rotary screen is driven by a Poncelet water wheel, actuated by the sewage, and is very effectual. The filtering, discharging, and regulating the flow of sewage into the filters are controlled by Adams' automatic apparatus.* The advantage of the apparatus is that there are practically no working parts to get out of order, and labour is dispensed with.

Experiments prove that coarse grain filters worked on the contact principle, may be constructed of a numerous class of materials, and that different districts may adopt materials which are obtained locally, and often at a small cost, although it may be observed that porous coarse-grained material, such as coke and burnt ballast, effect a greater degree of purification than do fine-grained impervious materials such as granite, slate, etc.

The total cost of the farm when formerly worked on the chemical precipitation and broad irrigation system was for the year ending March 31st, 1895, £15 11s.11d. per million gallons (taking into account the amount earned by the farm and sale of sludge, which was £117 7s.); it is now £3 19s. with the biological system."

At present only part of the sewage is treated bacterially. The beds have been working for the last four years, the coarse bed dealing with the screened sewage at the rate of about 100 gallons per square yard per day, and the fine bed at a rate of 150 gallons per square yard per day; 10 acres of beds are, therefore, required to treat three million gallons of sewage per day after it has been properly screened.

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* Chapter XII.

In June, 1899, in connection with an enquiry at Newmarket, I was asked to make a special examination of the Sutton results for the Local Government Board. The samples of raw (screened) sewage, coarse-bed effluent, and fine-bed effluent were so collected as to represent the working of one pair of beds on one day, the average samples being obtained by taking equal volumes at intervals of five minutes throughout the whole period of filling or discharge.

The gaugings of the two beds were given to me as—

Coarse bed	6600 gallons
Fine bed	4369 „

The volume sampled was, therefore, approximately 19,800 gals. of screened sewage, of which 13,107 gallons was subsequently passed through the fine bed.

The area of the coarse bed was 33 × 55ft. = 201⅔ sq. yds., and it was therefore dealing with the liquid at the rate of 102 gallons per sq. yd. per day, while the fine filter with an area of 83·3 sq. yds. dealt with the coarse filtrate at the rate of 157 gallons per sq. yd. per day, or approximately for the double filtration, ten acres for three million gallons of screened sewage.

My analytical results are summarized on p. 179.

The distribution of the liquid over the beds at Sutton is still of the simplest type: a single gutter, with a distinct slope, runs centrally to within about two feet from the end. The entering sewage runs down at first to the further end of the bed, then as that fills up it mounts higher and higher in the trough till it reaches the near end. The effect is that the parts of the ballast below the end of the trough have to deal with nearly the whole of the incoming sewage, while the material at the near end only becomes slowly saturated with the liquid rising from below. The discharge is made by drain pipes laid on the foundation of the bed, therefore is fairly even for the whole surface. But this irregularity of contact between the material and the liquid revealed itself in some of the figures of the individual analyses.

The suspended solids in passing the coarse bed fall from 61 to 18, the difference of 43 must be retained. Its liquefaction, as I have pointed out, is mainly an anaerobic process, actually antagonistic to the oxidizing and nitrifying changes which are intended to occur in the fine bed. It is proved, however, by the increase of combined nitrogen in solution from 3·4 to 4·1 parts,

		Solids.			Cl	O con-sumed	Nitrogen.						'Percentage purification.		
		Dis-solved.	Sus-pended.	Total.			As Nitrite.	As Nitrate.	As free NH_3	Albd. NH_3	Orgc. N	Total N	By O con-sumed.	By Albd. NH_3	By Orgc. N
A	Raw Sewages	97·03	60·9	157·93	11·47	2·944	0	0	3·007	·493	3·115	6·122	—	—	—
B	12 individual samples, Coarse beds	88·19	18·35	106·54	9·83	1·486	·235	·553	1·066	·226	1·516	3·47	50	54	51
C	Coarse bed filtrates	86·6	15·2	101·8	9.78	1·461	·186	·73	1·112	·202	1·408	3·436	51	59	55
D	12 individual samples, Fine beds	94·96	0	94·56	9·57	0·815	·157	3·18	0·33	·147	0·372	4·039	73	70	88
E	Fine bed filtrates	97·83	0	97·83	8·53	0·833	·108	3·33	0·343	·147	0·39	4·171	72	70	87

For purposes of comparison I append the results of the averages calculated to a uniform content of 10 parts per 100,000 of chlorine.

A		84·3	53·0	137·3	10·0	2·55	0	0	2·61	·43	2·7	5·32			
B		90·0	18·6	108·6	,,	1·52	·240	·563	1·09	·23	1·64	3·54	40	47	40
C		88·5	15·6	104·1	,,	1·49	·188	·745	1·12	·205	1·42	3·48	42	52	47
D		99·0	0	99·0	,,	0·85	·171	3·33	0·345	·154	0·39	4·21	66	64	86
E		114·0	0	114·0	,,	0·98	·126	3·90	0·402	·172	0·46	4·9	62	60	83

Calculated from the above table, the ratio of nitrogen to chlorine, and the percentage of oxidation are as follows:—

Average.	Chlorine	Total N.	R. $\frac{N \times 100}{Cl}$	Percentage of Oxidized N.	
				On original.	In Sample.
A	10	5·32	53·2	0	0
B	,,	3·54	35·4	15·1	22·7
C	,,	3·48	34·8	17·3	26·5
D	,,	4·21	42·1	66	83·1
E	,,	4·9	49·1	75·7	82·2

that the fine bed has had in this case to supplement the coarse bed in dissolving nitrogenous solids.

The general lowness of the free and albuminoid ammonias with high organic nitrogens is probably explained by the fact that the effluents were analysed in such a fresh state that the nitrogen was mainly present as urea, since this compound does not readily yield its nitrogen by distillation with alkali or permanganate, but is completely changed into ammonia by the Kjeldahl process, hence would appear as organic N. It is well known that before urea can be nitrified it must be hydrolysed into ammonia: the first stage should be effected in the coarse bed, the second in the fine.

On the other hand, during the 13 hours of rest and aeration that had elapsed before the first samples were taken, the coarse bed had temporarily assumed a nitrifying function, as shown by the very considerable amounts of nitric nitrogen found, with a lower quantity of nitrite, and only a slight reduction of the oxygen consumed. Later in the day, when the rest periods are shorter, all this nitrate disappears, with a heavy fall in the total nitrogen, and a considerable lessening of the oxygen consumed. There is little doubt that this is explained by a Gayon and Dupetit reaction, by which nitrates and organic nitrogenous matter decompose one another, the oxygen of the nitrate burning up the carbon, and nitrogen or oxides of nitrogen being evolved as gas. Possibly the disturbance occasioned by the formation of this gas accounts for the extraordinary variations in individual samples, and for the high suspended matter occasionally met with.

In this case we have actually a reversal for a time of the functions of the two beds, and a violation of the law that "the bacterial changes should be carried out with regularity and in natural sequence."

A great divergency was noticed in the successive individual samples, taken at 15 minutes interval, and can be accounted for by the interference of the filling material with the free mixing of the sewage, so that zones and channels are formed through which the liquid flows at varying rates. The effluent issuing at successive intervals of time comes from different layers and parts of the beds, and really represents sewages of different hours or even days, as proved by the individual chlorine figures.

At Oswestry the Sutton system was adopted in the beginning of 1898. The material for the beds was obtained by screening from an old refuse tip, from which, according to the engineer, everything excepting hard carbonaceous matter had disappeared. The coarser portions are used for the "primary" filters, 4½ feet deep, corresponding to the Sutton "bacteria beds," and the intermediate portions for the "secondary" filters, 4 feet deep, intended to be equivalent to the Sutton coke breeze. This screened refuse costs about 1s.3d. per cubic yard in the filter beds, and is believed to be already charged with organisms. The crude sewage is not passed at once on to the beds, but is previously clarified by subsidence in settling tanks. The report states that about half the sludge settles in these tanks, and is removed weekly, mixed with the dust screened out of the town refuse, and sold as manure. The population of Oswestry is 10,000, the dry-weather sewage 300,000 gallons per day, and the water supply 20 gallons per head. Total costs of works (when completed), £1,800; annual working expenses about £80.

Other experiments carried on with the Sutton method on the sewage of Leeds in 1898, at first showed considerable difficulties owing to "sludging-up" of the beds, but by increasing the periods of rest so as to allow the retained organic matter to be dissolved, and by the introduction of finer screens, which remove a greater portion of the suspended solids (sludge) to be otherwise dealt with, more satisfactory results were obtained.

It is remarked, however, in the Leeds report, that if the resting period was too prolonged, "the large increase of capacity gained by rest was, to a great extent, lost within a short time." Thus after a suspension of 38 days, the capacity was reduced in a fortnight from 56,500 to 45,800, or 10,700 gallons. I would venture to suggest as a reason that the long aeration had destroyed or enfeebled the anaerobes, and that the liquefaction was therefore suspended until an anaerobic state was restored.

Colonel Harding (the Lord Mayor) and Mr. Hewson, the City Engineer, who together drew up the report, conclude as follows:—

"The question is raised as to whether an experiment should not be made without delay to ascertain the effect of the septic tank treatment for the destruction of the solids in suspension; also to see how far an open septic tank, or upward septic filtration through coarse material, covered with a layer of sand, would be effective in destroying the sludge, and so far relieving the filter beds."

With Leeds sewage, the experience gained shows that 400,000 gallons per day can be dealt with on ½ acre of coarse bed and ½ acre of fine bed, or 1 acre per day in all, after the grit has been removed in a settling tank, and the grosser solids (paper fibre), etc.,) screened off. This gives a minimum of 50 acres of beds, for 20,000,000 gallons; but in order to have spare beds, it is recommended to have 70 or 80 acres, or say 4 acres per 1,000,000 gallons.

Leeds, under the old system, would have to deal with 300 tons of sludge per day, or say 100,000 tons per annum. By settling the grosser solids, the suspended matter could be reduced, according to the same report, from 37·2 grains per gallon to 25 grains per gallon, and the filter beds would not then sludge up. This leaves, however, about one-third of the total quantity, corresponding to the 100 tons of sludge per day of the present precipitation process still to be disposed of.

Since that date experiments have been carried out, and good results have been obtained, with either open or closed septic tanks; after working 14 months, nothing being withdrawn, "the tank was no fuller of sludge than six months ago," and the purification, after passing through coke, was 90%. The City Council have now approved the purchase for £85,000 of the Gateforth estate of 1882 acres of light loam over red sand, to which the raw sewage will gravitate 14 miles through a culvert, to be dealt with by septic tanks and coke beds, with irrigation of the effluent if necessary. For the biological treatment only 200 acres are required.*

"Sutton," or "Dibdin" beds have been adopted at a large number of places. At Manchester, experimental filter beds on the same principle have been named "double contact beds."

As it became gradually evident that the two beds, coarse and fine, even with preliminary screening or sedimentation were not exactly adapted to the *three* processes of bacterial change that we have mentioned, a third bed, or "triple treatment," was in many places adopted. In the Manchester enquiry of 1899, it was stated that if the "double contact" did not suffice, they would employ a "third contact."

An example of this triple treatment is found in the Hampton Sewage Works in the beginning of 1899. Much engineering skill was required to overcome the difficulties of level. The sewage, as it is forced to the out-fall by air compression, passes through screens on to a triple series of Dibdin beds in terraces, with 5 beds in each terrace, the upper beds being 34ft. by 50ft. by 4ft. deep, filled with clinker that has been rejected by a screen with ½-inch mesh; the middle beds 35ft.6in. by 54ft. by 4ft. deep, of clinker passed by ½-inch mesh, freed from dust; the lower 35ft.6in. by 58ft. by 4ft., "filled with finer material which might be called clinker sand."

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*Leeds City Council, April, 1900.

Each bed is allowed one hour for filling, one for standing full, one for emptying, and four to five for resting empty and aerating, giving three turns in twenty-four hours. The results are reported to be excellent, and no complaint has been made by the Thames Conservancy. In conformity to the requirements of the Local Government Board, the effluent is raised by an air-lift, discharged on to 20 acres of gravel land, thence passing through sub-drains into an effluent pipe 3 miles long, delivering into the Thames below the water companies' intakes. It is officially stated that the effluent instead of being improved, actually "becomes deteriorated by being passed through the land."

Population of Hampton 6900, dry-weather flow of sewage 154,000 gallons, sewage actually treated 69,000 gallons (25 gallons per head). Area of beds in square yards:

Coarse	944
Fine...	1065
Sand	1137
	3146 = 0 65 acre

"Cost of 15 bacteria beds in concrete, including all material and effluent aerator lift, £2970 2s.7d.," or about £4570 per acre. I refer later to another example of treble Dibdin filtration.

Dr. Kinnicutt, director of the chemical department of the Worcester (Mass.) Polytechnic Institute, writes (March 3rd, 1900):

> "In America, or in Massachusetts, sewage is successfully treated bacterially by the intermittent filtration method, and at the rate of 50,000 to 90,000 gallons per acre per day; but we have had no experience with the English method of bacterial treatment, namely, contact beds, as all the towns so far called upon to treat their sewage have had sufficient sandy soil to use intermittent filtration beds, and the cost of this kind of land is so little that beds of this character can be constructed at a much less price than the contact beds."

CHAPTER X.

BACTERIAL PURIFICATION (*continued*).—Capacity of Filters—Nature and Size of Materials—Gases in Filters—Depths of Beds—Aerating Processes—Lowcock—Waring—Ducat—Artificial Warming—"Thermal Aerobic"—Continuous Filtration—Salford—Stoddart's Filter.

THE regulations of the Local Government Board as to filters are at present :—

(1) Each set of filters (*i.e.* both coarse and fine) must be of sufficient capacity to contain the normal dry-weather flow for twenty-four hours. Coarse-grain beds can hold 25 per cent. sewage and fine beds 33⅓ per cent. This means, taking an eight-hour cycle, that the beds will be large enough to deal with three times the dry-weather flow, *i.e.* one volume normal, two volumes storm water.

As to material, its size and mode of arrangement have been shown to be more important than its kind. Coke breeze from its porosity exposing a larger surface was recommended by the Barking experiments and has been generally adopted. But it is somewhat expensive when required in large quantities, therefore in many localities local material, when properly screened and graded, can be employed. We have already referred to the use of old town-refuse at Oswestry.

Dr. Bostock Hill, in a paper at the Leeds Sanitary Congress in 1897, reported very favourably on fine coal as a medium for the filtration of chemically precipitated effluents at Wolverhampton, Lichfield, and other places. The sewage of the former town is heavily polluted with chemicals, that of Lichfield contains a large amount of brewery refuse. I cannot see how the action of coal is different from that of other media, but Dr. Hill contends that effluents from coal filters show a greater loss of organic carbon as compared to organic nitrogen than in filters made of other materials, and that this is a characteristic property of coal.

"As far as is known, any kind of coal will do, but it should be as clean as possible, and the depth should not be less than five feet." At Lichfield the first layer, over the drain pipes, is ½in. cube coal, then a little ¼in., afterwards 2½ feet of 1-8th in. cube, and 2½ feet of 1-16th in., ending with 6 inches of 3-16th coal dust. The liquid is supplied continuously for 12 hours, with 12 hours rest, and the rate is a million gallons per acre per day. The effluent is said to be bright and clear. He adds that "as a result of 12 months working the efficacy of the coal has increased. At first it would appear that the action is a chemical one, because the oxygen absorbed is at once directly affected; afterwards, however, nitrates are produced in considerable quantities, so that probably there is then a double action, chemical and bacteriological. The interior of the filter, after many months, has nothing but a slight earthy smell." This filter was introduced by Mr. Garfield in the summer of 1896.

Mr. Fowler, in his report of the Davyhulme experiments in 1897, confirms the results of previous observers that coal and burnt clay filters, when worked continuously, rapidly become clogged, and that improved results are obtained with intervals for rest and aeration. He considers coal to be superior to burnt clay.

The table given in Chapter XI. of the comparative nitrification effected by different filters, places the Garfield Filter as lower than other forms, but as already mentioned, this result is more likely due to the difference in the mode of working and aeration of the filter than to the material.

Partly for the sake of cheapness, and also because it was expected that coke would in time disintegrate, the use of more compact materials has been suggested. Broken slate* or shale has been much used in the north, and Thudichum even made laboratory experiments with pounded glass, and found a certain amount of efficiency. Burnt ballast, clinker, cinder, slag, polarite and iron sand have their advocates. Non-porous materials might be expected to have a lower capacity, but it is mainly on the surfaces and not in the interior of the masses, that the bacterial action occurs. At Exeter, Mr. Cameron expresses a general preference for clinker: at Southampton and other places assorted clinkers from the dust-destructors are used. But coke, if available, seems the best material for nitrification, and has shown no noticeable disintegration in nine years. Burnt ballast must be carefully made, as many kinds crumble and block up the filter.

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*At Festiniog slate filters were suggested at a Local Government Board enquiry in November, 1898, but the Board have not yet sanctioned the loan (January, 1900).

The enormous quantities of waste material in the neighbourhood of various collieries and ironworks have recently been utilized for the recovery of the "tap-cinder" which they contain, and Messrs. Wake and Hollis, of Darlington, have devised a plant for separating the whole by machinery into tap-cinder, coke-breeze, clinker, broken bricks, and "carbonaceous iron sand,"* the latter being proposed by them as a suitable and cheap material for bacteria beds. Its content also of iron oxides, with a trace of manganese, suggested the action of these substances as carriers of oxygen to the organic matter (p. 145). But, as in coke, which also contains them, and in many patented materials prepared by ignition, the density and insolubility make their chemical action very slight, and quite subordinate to their use as strainers and bacterial surfaces.

The sewage at Spennymoor, Durham, has been treated on filter beds made of this material, placed in the filters without further grading. The best results are stated to be obtained with a bed of 2ft. to 2ft.6in. deep, 9in. of crushed and graded fire-brick (also from the waste heaps) being placed over the drain-pipes at the bottom. The sand has also been used for treating the overflow from cesspools in connection with isolated dwellings, and for filling foul ditches.

Dibdin and Thudichum have compared this carbonaceous iron sand with other materials in some experiments on triple filtration of crude sewage "with the usual solid matters suspended in it." In each set the size of the grain was :—

First bed, passed by $\frac{1}{2}$-in. mesh and rejected by $\frac{1}{4}$-in.
Second ,, ,, ,, $\frac{1}{4}$-in. ,, ,, ,, ,, $\frac{1}{8}$-in.
Third ,, ,, ,, $\frac{1}{8}$-in. ,, ,, ,, ,, $\frac{1}{32}$-in.

After five weeks running with two fillings per day, the effluents were analysed. The composition of the crude sewage, calculated to parts per 100,000, is given as :—

Free NH_3 13·53, Albumd. ·740, Oxygen consumed 9·14

The effect in reduction of these figures, or "percentage of purification," the water capacity at this stage, and the nitrogen oxidized, is shown in the annexed table.

---

*An analysis by W. F. K. Stock gives—moisture 6·75, FeO 30·41, Fe_2O_3 10·33, carbon 7·53, rough sand 16·70.

COMPARATIVE EFFICIENCY OF DIFFERENT MATERIALS.

	Percentage Purification.									Water capacity per cent.		Progress of Nitrification. N as Nitrates and Nitrites. Parts per 100,000.		
	By first bed (single treatment).			By first and second (double treatment).			By all three (treble treatment).			First or coarse bed.	Third bed.	First bed (s'gle).	First and second (d'ble).	All three (treble).
	Free NH_3	Alb. NH_3	O abs'd	Free NH_3	Alb. NH_3	O abs'd	Free NH_3	Alb. NH_3	O abs'd					
1.—Three beds of carbonaceous iron sand	44	13	46	71	46	67	99	80	81	34·6	28·2	0	·090	3·67
2.—Three beds of coke breeze	28	16	44	55	22	63	92	68	68	41·5	38·7	0	·580	4·27
3.—Two beds coke breeze followed by one bed sand	32	increased	44	62	39	64	99	88	91	41·5	10·0	0	·681	5·89
4.—Three beds of burnt ballast	36	,,	45	67	51	68	97	80	80	28·7	33·3	0	·614	4·15
3.—Three beds of animal charcoal	52	7	79	77	64	85	99	90	95	34·6	25·2	0	1·210	3·68

From it we may gather the following conclusions :—

1. With reference to material, the iron sand shows in this case a slight superiority over the coke breeze alone, but, in the words of the report, "it was practically identical in work effected with the other materials, and there was no specific advantage in the use of any one material more than another, so far as the chemical results were concerned . . . . Observations were made as to the bacteria in the respective effluents, but no specific advantage seemed to be shown by any one material in this respect."

As in the Massachusetts, Barking, and Berlin experiments, the sacrifice of capacity and of output on substituting a less porous material like sand, was not accompanied, in the case of sewage, by an equivalent advantage in purification.

2. That no nitrate or nitrite was produced in any case in the first beds is a strong indication that they were acting hydrolytically and anaerobically, their function being that of an "open septic tank."

3. The double filtration, or result of the second bed, cannot be exactly followed, as the nitrites are not separately given, but it corresponds mainly with the second stage of partial oxidation.

4. In the treble contact, the coke breeze has shown a higher power of nitrification, as noticed by other observers, owing, undoubtedly, to its greater porosity.

It is also important to note that these filters show that the organic carbon is more easily oxidized than the organic nitrogen, and confirm my criticism on the use of coal (p. 185).

To study the influence on nitrification, in October, 1899, I examined 6 tray filters after running about three months with a hydrolysed sewage. D, E, and F, had an area of 100 sq. ft. each ; A, B, and C, were ⅙ the area, and had become much clogged. D was most freely exposed to the air. The filtrates gave on successive days the averages in parts per 100,000 on p. 189.

Denitrification with loss of nitrogen is here shown by those filters which are not in proper order. The superiority of a graded filter (F), is also evident, while coal has exhibited the peculiarity that has been noticed in other cases, of encouraging the production of *nitrites*. Filter F shows the extraordinary nitration of a strong sewage, resulting in an excellent effluent ; in these cases a gain of total nitrogen, presumably from the air, has often been observed. The great variation produced by the ventilation and aeration of similar filters is also seen in comparing B, D, and E.

INFLUENCE OF MATERIAL ON NITRIFICATION.

	Fine Coke.		Coarse Coke		Coal		Coarse Coke near first door.		Coarse Coke near second door		Three trays of fine coke below, four of coarse above.	
Bays	A		B		C		D		E		F	
Day	1	2	1	2	1	2	1	2	1	2	1	2
N as NH_3	10·3	7·8	11·3	7·4	9·8	8·2	4·5	2·9	7·0	10·7	1·64	1·24
,, Nitrous	0·592	0·666	·814	·740	4·44	2·96	0	0	·370	·148	0	0
,, Nitric	8·0	9·55	6·35	5·48	7·75	5·48	24·5	28·5	13·8	9·55	29·0	29·8
,, total inorganic	18·892	18·016	18·464	13·620	21·99	16·64	29·0	31·4	21·17	20·398	30·64	31·04
Relation of oxidized N to one of ammoniacal ...	0·83	1·3	0·63	0·84	1·24	1·03	5·4	9·8	2·02	0·9	18·0	24·0
Degree of colour	4	2	10	6	5	3	2	2	4	3	1	1
Appearance	Deposit	ditto	Much black deposit	ditto	Deposit	ditto	Fairly clear.	ditto	ditto	ditto	Clear	ditto
Estimated disappearance of N per cent	37	40	39	55	27	45	3	Gain	30	32	Slight gain	Gain
Dissolved Oxygen in cc. per litre							6·8	6·71	7·03	6·58	5·44	6·33

With reference to porous materials the conclusions of the Manchester Report* agree with previous experience in finding

"1. That the initial capacity of a contact bed is practically uninfluenced by the grade of material with which it is filled.

"2. That there is a rapid decrease in capacity during the earlier period of working [before the resolving bacteria become established and active]."

After noticing the increase of capacity during a period of rest, the report concludes, that coarse cinders, 3in. to 1in., permit too free access of sludge to the body of the filter and even into the drains, while "if the material is too fine the beds soon become quite impervious to sewage." With bed C, ¾ to ¼in., followed by D, ½ to ⅛in., they obtained better results, but their final opinion is that the most suitable material for bacterial beds consists of clinkers passing through 1½in. mesh and rejected by ⅛in.

In common with other observers, it was remarked that "contact beds, after a comparatively short space of time, acquire a practically constant capacity," this is usually found to be about 33%.

The final deductions were: that the suspended matter must be removed as far as possible by sedimentation, and that any not so removed should be retained on the surface of the bed; that the surface must be raked or forked over about once a month, and that periodical intervals of rest must be allowed.

It will be remembered that in the London County Council investigations of 1899 (p. 171), one of the objects was the effect of "double treatment," that is, by an extra coke bed. Unfortunately, the name might lead to misunderstanding, as "single treatment" meant two coke beds, the first with gas coke, "the size of walnuts," corresponding to an anaerobic tank, and about 4ft. deep; the second a bed of 6ft. thickness, called the "primary bed, for the first stage of double treatment"; while the third was called the "secondary coke bed," corresponding, however, to what is commonly named "treble treatment." The coke in each bed was the same size. The primary and secondary beds were "matured," or inoculated, by frequently charging with crude sewage for about three months to seed them with bacteria.

In order to test the aeration of the 6ft. beds, and of the 13ft. that were constructed afterwards, the same plan was followed as I used at Exeter, in 1896, of sinking vertical pipes into the bed and aspirating the gas for analysis.

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*Baldwin Latham, P. Frankland, and W. H. Perkin, October, 1899.

The amounts are given as follows:—

Six-foot depth.			Thirteen-foot depth.		
Number of hours since Sewage drained off.	Percentage of Oxygen in Air.	Percentage of Carbonic Acid in Air.	Number of hours since Sewage drained off.	Percentage of Oxygen in Air.	Percentage of Carbonic Acid in Air.
4	19·8	0·4	22	18·4	1·4
22	9·8	5·8	26·75	14·0	3·8
24·5	10·0	6·0	50·75	14·8	3·0
37	17·8	2·0	51·25	15·3	3·3
40·5	16·8	2·4	70	14·7	0·8

A supplementary report (Oct. 26th, 1899) states that the experiments have been repeated and the results corroborate the above. The quantities are irregular, but show that a reduction of the free oxygen occurs from the 20% which is normally present in air. The carbonic acid produced obviously corresponds to an equivalent diminution of the organic carbon. A point to notice is that with the presence of gaseous carbonic acid, there must be an additional quantity, proportional to the vapour tension, retained dissolved by the liquid in the interstices of the coke. Several observers have proved the inhibiting action of carbonic acid on bacteria, especially those which are oxidizing, therefore it is important when the third or oxidizing stage is reached, that the carbonic acid should be removed by free circulation of air as soon as formed, or the failure of nitrification noticed in so many of these filters will follow.

With the same object, at Exeter, on November 12th, 1896, I sunk "compo" tubes to different levels in filter No. 2, 5ft. deep, which had been in constant work for several days, and aspirated the gas for analysis two or three hours after the last discharge. The results were:—

	Air.	Tube 1, 18in.	Tube 2, 36in.	Tube 3, 54in.
Per cent. of CO_2 by volume	0.04	0·375	0·98	0·75
Relation to volume in air	1	9·4	24·4	18·8

Assuming the air in each empty filter to contain one per cent. of CO_2, it follows that the volume of carbonic acid removed as gas is also 1% of the volume of sewage dealt with in the filters.

The weight of organic carbon destroyed in this way is therefore about 50lbs. per million gallons, or ·5 parts per 100,000, without reckoning the dissolved CO_2 in the interstitial liquid.

Probably on account of the interference of this carbonic acid in deep filters or by reason of the beds not having been working for sufficient time, the purification reported by Dr. Clowes, even by his " secondary " (really treble) treatment is not equal to what has been attained elsewhere. He states that " the purification effected by a single treatment of the raw sewage in the coke-beds amounts to a complete removal of the suspended matters, and to a further removal of at least 51·3% of the dissolved putrescible oxidizable matter. The primary 6-foot coke-bed actually removed on the average 49·9% of dissolved impurity, and a second process has effected thus far an additional purification of about 19·3%, giving a total average of purification of the *clarified raw sewage* amounting to about 69·2%."

With the deeper filter, *Engineering* calculates that, taking the daily dry-weather flow of London sewage at 200 million gallons, and the rate of filtration at three million gallons per acre, nearly 70 acres of filter 12ft. deep would be required, taking 450,000 tons of coke.

We revert to the processes depending mainly on strong aeration, of which the chief are Lowcock's, Waring's, and Ducat's. In Chapter V., p. 94, we have given a table of the volumes of air required to oxidize the *nitrogen* of organic matter : a further quantity would be demanded by the carbonaceous matters, measured approximately by the " oxygen consumed " figure (p. 30). We have seen how in an effluent that has properly passed through all the stages, the residual organic carbon can be disposed of by the nitrates, in presence of the appropriate organisms ; but for an imperfectly hydrolyzed effluent, and still more for a raw sewage, a large volume of air is required, and the action is apt to be slow, irregular, and incomplete. This is well shown in some experiments of Mr. Gilbert Fowler's,* wherein a chemically precipitated effluent (lime and copperas) was exposed to the air in thin layers, protected from dust, for various periods and under different conditions.

In no case was sufficient oxidation effected in 24 hours to render the effluent subsequently non-putrefactive. Even after 72 hours exposure, putrefaction took place on afterwards incubating.†

*[*] *Manchester City Surveyor's Report* for 1897. †See also Chapter V., p. 95

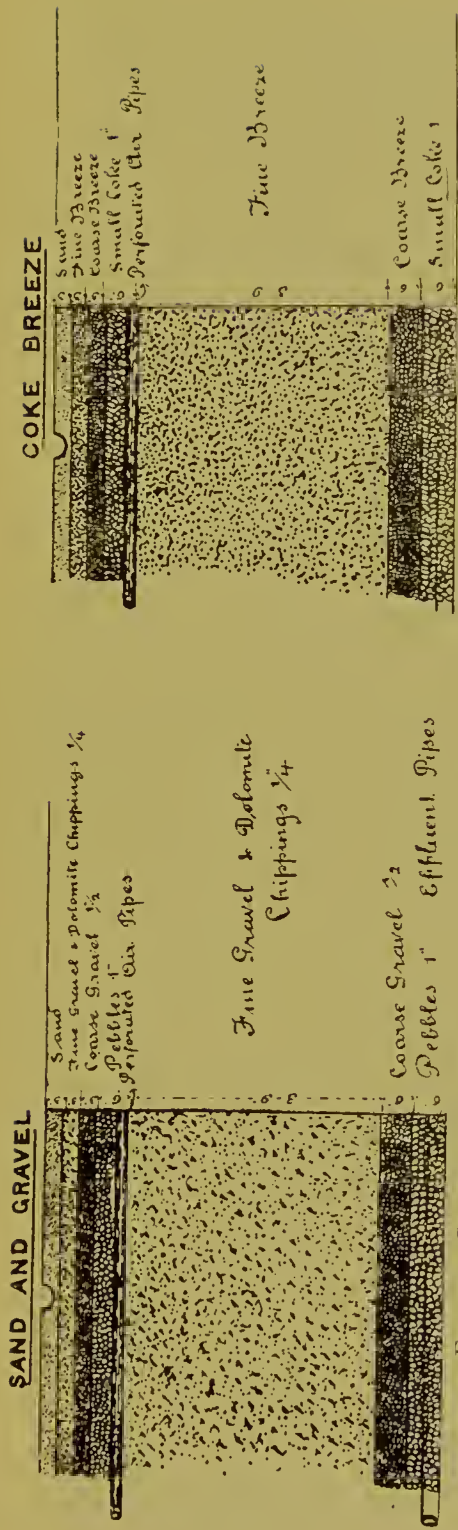
COKE BREEZE
Sand
Fine Breeze
Coarse Breeze
Small Coke 1"
Perforated Air Pipes
Fine Breeze
6' 6"
Coarse Breeze
Small Coke 1"
SAND AND GRAVEL
Sand
Fine Gravel & Dolomite Chippings ¼
Coarse Gravel ½
Pebbles 1"
Perforated Air Pipes
Fine Gravel & Dolomite Chippings ¼"
6' 6"
Coarse Gravel ½
Pebbles 1"
Effluent Pipes

FIG. 22.—SECTION OF LOWCOCK'S AERATED BACTERIAL FILTERS AT MALVERN AND WOLVERHAMPTON.

Mr. Lowcock, at Malvern, in 1892, forced in air at a mean pressure of 4½ins. of water. He used* a pressure varying from 3·4 to 6 inches, but bearing no relation to the volume of liquid which flowed continuously through the bed. At Malvern the filter was made of sand and gravel (Fig. 22), and later, at Wolverhampton, of sand and coke breeze. *The sewage had been screened and chemically precipitated and sedimented before entering the filters.* "The quantity applied when the most satisfactory results were obtained was at the rate of 263,780 gallons per acre per day, so that at this rate the area required per million gallons of effluent of the same impurity as that experimented upon would be 3·8 acres. The dry-weather flow of the sewage experimented upon is 16 gallons per head per day of the population, so that the quantity treated at the most efficient rate is equal to that from 16,486 persons per acre."

The following table summarizes Mr. Lowcock's results in October, 1895 :—

"Analysis of the effluent from the settling tank as applied to filter, and the resulting effluent from filter in parts per 100,000.

---

* *Proc. Inst. C.E.*, 1893.

October 8th, 1895.	Tank effluent applied to filter.	Effluent from filter.	Percentage of reduction.
Free Ammonia	4.00	1.20	70
Albuminoid Ammonia	0.35	0.07	80
Oxygen consumed	1.70	0.40	77
Nitrogen as nitrites and nitrates...	traces	2.68	
Chlorine	20.00	24.00	

The percentages of reduction are calculated on the tank effluent; if calculated on the sewage, the results of the whole treatment, tank and filter, would be a reduction of considerably over 90 per cent.

The Wolverhampton sewage is a most difficult one to deal with, as it contains a large quantity of manufacturers' and acid waste."

In the Lowcock filters constructed at Tipton in 1896, the sewage had also been preliminarily treated with lime and alumino-ferric in precipitating tanks. The filters were 3½ft. deep, with a bottom of coarse coke, a body of coke breeze, and a top layer of fine broken limestone and sand. *The outlets of the filters are always open*, and during the supply of clarified effluent for twelve hours daily, air is forced in at a pressure of ½in. of water. "Since August, 1898, the rate of flow has been at the rate of 240 gallons per sq. yard per day." The analyses given as an average of nine months are :—

PARTS PER 100,000.

	Solids.			Cl.	Ammonia.		Oxy. Abs.	Nitric N.
	In solution.	In suspension.	Total		Free	Alb.		
Tank Effluent	82·7	1·6	84·3	10·2	1·25	0·23	0·77	Nil
Filter Effluent	80·7	1·4	82·1	10·0	0·27	0·05	0·22	0·74

"thus showing a purification of the tank effluent of 75·7% calculated on the organic ammonia, and 68·5% on the oxygen absorbed; if calculated on the raw sewage, these percentages would work out at over 95%."

On this filter, Mr. Mansergh, in his report to the Baltimore Sewage Commission 1899, remarks :—

> "It would seem that the supply of air into the filter enables the bacteria to increase their activity, but the recent practice of resting the filter for 12 hours each day, tends to show that natural aeration

> is necessary to the smooth working of the system. The original idea that the mechanical forcing of air into the filtering material would enable the tank effluent to be applied continuously, has been modified by the adoption of the half-day intermittent working, and this result tends to support the Dibdin process of alternate fillings."

In 1894, Waring obtained permission to treat a portion of the sewage of Newport, New York, by a method of forced aeration which differs from Lowcock's mainly in the separate treatment of the sludge by means of "aerators."

This city was sewered under the combined system, and the liquid became frequently admixed with sea water entering the sewers, the effect being an increase of the suspended solids by precipitation of soap and other matters. This precipitation has been often noticed in tidal reaches, and has resulted in the formation of banks and deposits on the bed. It would seem that the lime and magnesia present in ordinary waters does not secure the removal of all the higher fatty acids, as a greasy scum is seen frequently in sewers. From examination of the soluble part of sewage I have found that soda salts of oleic and other fatty acids are still present, especially in towns with a soft water supply, owing probably to the influence of the ammonia formed. These soluble soaps are decomposed and precipitated by the high amount of calcium and magnesium salts existing in salt-water, so that the sewage of Newport contained unusual amounts of soap curds.

The sewage first passed through a settling chamber for road detritus, and was thence pumped alternately through either side of a divided tank containing a shallow bed of coarse broken stone to arrest the coarser solids. "The impurities in the section thrown out of use disappeared rapidly in its interval of rest."

The liquid next passed slowly through four straining tanks filled with stones and gravel whose function was said to be "mere mechanical sedimentation." As soon as these became clogged a plug was drawn, and the sludge emptied into a separate "aerating tank," filled with stones and gravel, where air was driven constantly through the mass, and as soon as active bacterial action had set in, the sludge was rapidly dissolved.

Air was also forced through the straining tank till it was again in condition for use. Apart from the complexity of the system, we have again in place of regular intermissions for rest and aeration, a continuous working, assisted by forced aeration, for long periods in the hope that in a given tank-capacity a larger volume of sewage could be treated. The action here is apparently entirely aerobic, and unaccompanied by previous hydrolysis.

Since these experiments were carried out several alterations have been made in the details, and installations have been constructed at Willow Grove Park, Philadelphia, and at other places in the States.

THE DUCAT FILTER.

Col. Ducat constructs an aerating filter with walls of 3-in. drain-pipes set nearly horizontally in Portland cement, the inner ends being 3in. lower than the outer, to prevent the sewage running out. The free exposure to air causes considerable cooling, rendering necessary a special provision by larger pipes for hot-water heating in winter to prevent freezing, and this introduces an element of expense. I understand that in recent installations of this filter, provision is being made for a breaking down of the organic nitrogen into ammonia before aeration, though it appears, by the analyses published in 1898, that in the filter at Hendon a large quantity of ammonia was carried off by the air without being nitrified. The organisms cultivated in this apparatus must obviously belong to the two classes of which *Bacillus nitrosomonas* and *B. nitrobacter* are types. The satisfactory continuous working depends after these growths have been developed, on an ample provision of oxygen. In this filter, as in others, a deficiency of air supply will reveal itself by a decrease in the activity of the colonies of *B. nitrobacter*, and therefore in the presence of larger quantities of nitrites.

The bed is coarse-grained above and fine below, and the action is intended to be exclusively aerobic, as atmospheric oxygen in excess is brought in contact with the contents at once without giving any period of anaerobic incubation, and therefore presents some points of resemblance to the Waring process already mentioned. I have already observed that in towns with long and old sewers, or where storage is practised, the liquids may have already received sufficient hydrolytic resolution to be quite prepared for strong aeration such as this filter supplies.

This is illustrated by an analysis furnished by Dr. Houston :—

	Oxygen absorbed.	Free ammonia.	Albuminoid ammonia.	Oxidised nitrogen.
Sewage, Oct. 14th, 1898 ...	14·72	8·7	1·6	—
Filter effluent, ditto	0·78	0·3	0·094	·477

The high free ammonia and the low albuminoid shows that the sewage has already undergone the preparation I have mentioned. The nitrification of the effluent, indicated by the "oxidised nitrogen," has not proceeded as far as might have been expected, notwithstanding the very large loss of ammonia, but I understand much better results have since been obtained. The oxidation of the carbonaceous matter to carbonic acid is also most marked. Dr. Houston's bacteriological examination of this filter has already been referred to (p. 64).

The Ducat system has been under trial at Hendon and Sutton, and was adopted for Market Drayton in May, 1899.

Figs. 23, 24, 25, and 26 are from Mr. Mansergh's Baltimore Report, 1899.

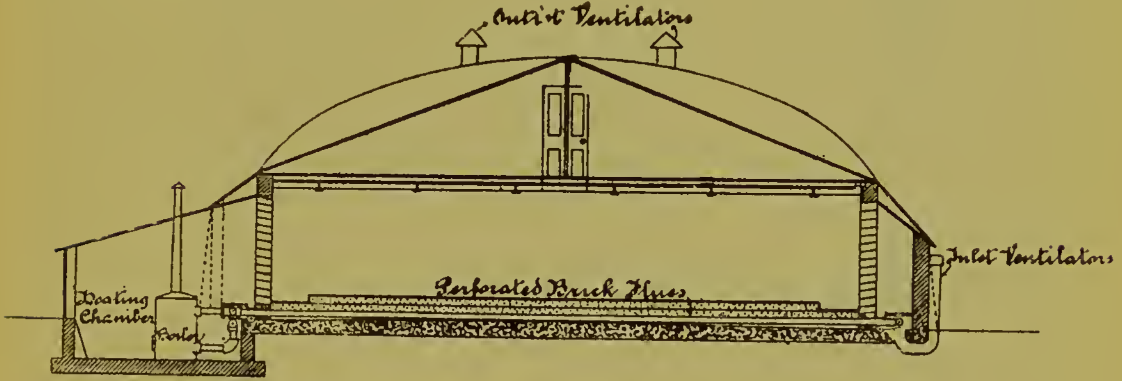
Outlet Ventilators
Inlet Ventilators
Perforated Brick Flues
Dosing Chamber
Boiler

FIG. 23.—SECTION OF DUCAT'S BACTERIAL SELF-ACTING FILTER.

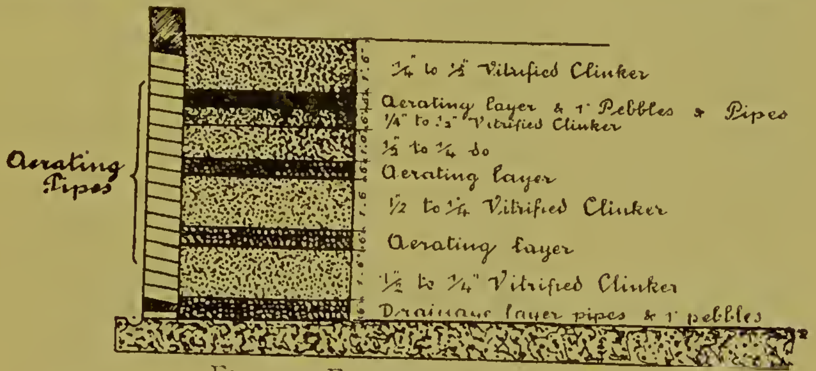
Aerating Pipes
¾" to ½" Vitrified Clinker
Aerating layer & 1" Pebbles & Pipes
¼" to ½" Vitrified Clinker
½" to ¼ do
Aerating layer
½ to ¼ Vitrified Clinker
Aerating layer
½" to ¼" Vitrified Clinker
Drainage layer pipes & 1" pebbles

FIG. 24.—FILTERING MATERIAL.

A great difficulty attending the processes aiming at the direct oxidation of sewage by currents of air, is the cooling produced, which in winter may actually occasion freezing. To avoid this, several inventors have introduced systems of artificial warming, with an additional view to stimulating the bacteria, but also with a considerable added expense. Colonel Ducat, as we have seen, provides a series of hot-water pipes for heating in winter. The

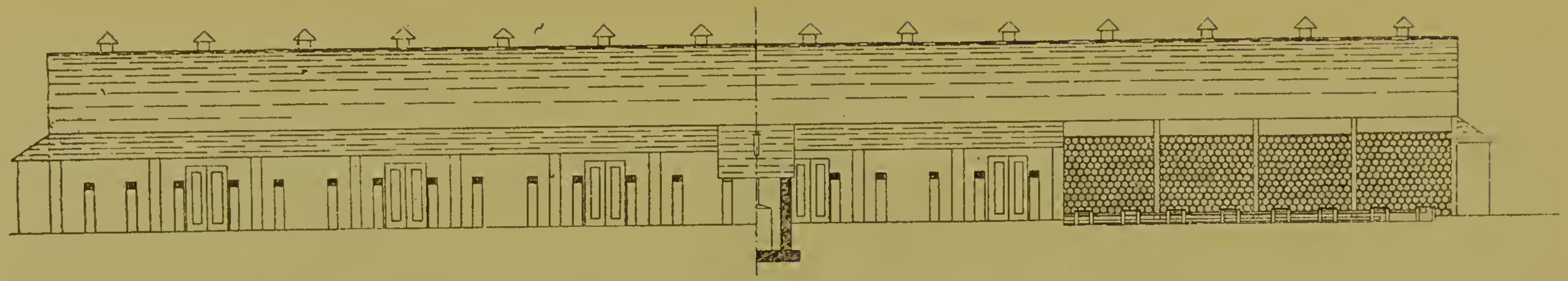

FIG 25.—LONGITUDINAL SECTION AND ELEVATION OF DUCAT'S FILTER.

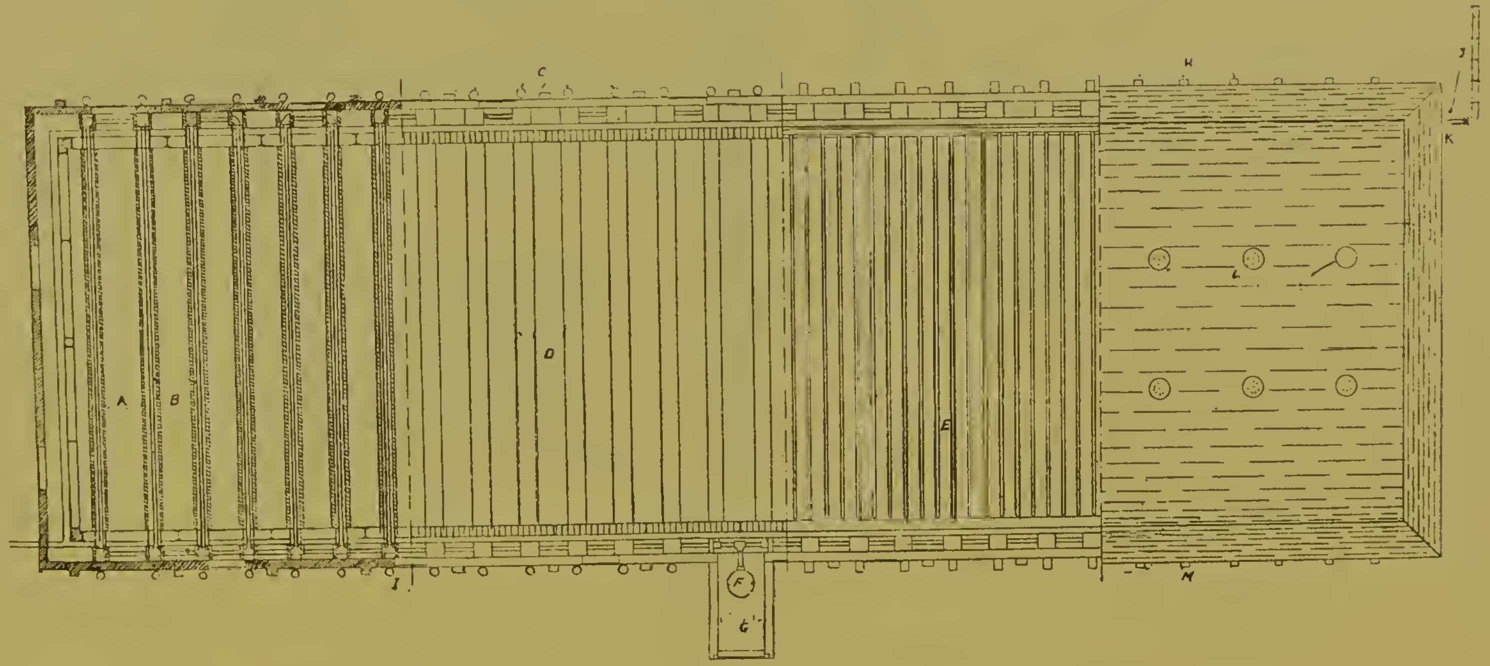

FIG. 26.—SECTIONAL PLAN OF DUCAT'S FILTER.

(*a*) Perforated Brick Flue; (*b*) Heating Pipes; (*c*) Inlet Ventilators; (*d*) Floor of Filter; (*e*) Automatic Tipping Channels; (*f*) Boiler in Heating Chamber (*g*); (*h*) Inlet Ventilators; (*i*) Outlet Ventilators; (*j*, *k*) Regulating Valve and Distributing Channel, with Weir Valves.

effect of cold in diminishing the activity of nitrifying organisms was proved repeatedly in the Massachusetts experiments, when the temperature of inception of active nitrification was found to be 39° F. A number of bacteria, however, are not affected by cold: in the L.C.C. Report of the Barking filter, it is said that it "was able to do its work satisfactorily during the exceptionally severe weather in January and February, 1895. A thin coat of ice was formed on the surface, but the filtration proceeded without intermission, *the only noticeable change being the decreased production of nitric acid*."

The idea of increasing the activity of organisms by raising the temperature within certain limits, is of course not new, being applied ordinarily in fermentations. But in connection with sewage it has been limited by the expense. In 1898, Whittaker and Bryant introduced their "Thermal Aerobic Filter," at Accrington. The plant included an "open septic tank," of which we shall speak further. The tank effluent is distributed over a filter bed of 2ft. broken stones, and 6ft. gas coke, with 12in. limestone chippings on the top, by means of an automatic revolving sprinkler, in the delivery pipe of which is placed a steam pipe, a small jet of steam being blown into the sewage just as it arrives at the sprinklers "to raise the sewage, and thereby the whole body of the filter to the required temperature." The heat also raises the temperature of the air in the filter, causing it to rise and thus allow fresh air to enter through the drains, so that better aeration is claimed to be produced in this way. The analyses given are:

RESULTS IN PARTS PER 100,000.

September 19th to October 19th 1898.	Oxygen absorbed in 4 hours	Albuminoid Ammonia.	Chlorine as Chlorides.	Nitrogen as Nitrates & Nitrites.
Raw Sewage	9.51	1·19	11·00	*Nil*
Tank Effluent going on filter ...	4·99	·562	10·88	*Nil*
Purification on Raw Sewage per cent.	47·5	52·8	—	—
Filter Effluent	1·81	·176	10·85	2·33
Purification on Tank Effluent ...	63·72	68·68	—	—
Purification on Raw Sewage ...	80·96	85·20	—	—
Final Effluent—Settled	1·47	·084	10·85	2·3
Purification on Tank Effluent ...	78.55	85·0	—	—
Purification on Raw Sewage ...	84·54	92·1	—	—

In their patent (1899—4460) they show that the capacity of the filter can be extended as desired without hindrance to its efficient aeration. The filters consist of several chambers, either circular or polygonal in form, placed in juxtaposition and filled with filtering material, the spaces between the circular polygons forming shafts or wells through which air can be drawn or forced. An air shaft is preferably arranged in the centre of each chamber. The beds of the filters are plain sloping surfaces, on which are laid perforated pipes, forming channels leading to the air-shafts, so that the filtering material filled into the chambers rests on a surface freely and uniformly accessible to air. The perforated pipes are so arranged that the open ends of the channels formed thereby are directly in communication with the central air shafts and the spaces between the chambers. By adding chambers at the sides the area of the filter can be increased to any desired extent.

The view shows the retaining walls and ventilating shafts, and also the beds of the filters which are formed of perforated half-pipes set close together. They are ready for being filled with the filtering material, which is ordinary unbroken gas coke, well forked so as to remove all the small material.

These filters are 61 ft. diameter, the filtering material being 9ft. deep. Each filter is capable of dealing with 200,000 gallons of sewage per day, which has previously passed through open septic tanks.

" The tank effluent is lifted by means of pulsometers and distributed on to the filters by automatically revolving sprinklers. These distribute the tank effluent uniformly over the surface of the filter, and passing directly into the body of the filter it is continuously trickling down over the surfaces of the filtering material in contact with fresh air and passes out through the effluent channel thoroughly purified."

The working of the filter is, therefore, continuous, not intermittent. Mr. Joseph Barnes, chemist to the Accrington and Church Sewage Board, reports that incubator samples are satisfactory. The plant for treating 200,000 gallons daily, covers 958 square yards. The entire daily flow being 1¼ million gallons, Mr. Barnes estimates that to raise the whole of the sewage five degrees would cost in coal at least £450 annually, 10° £900, and so on. He suggests that the scheme for burning refuse should be combined with that for sewage disposal.

Mr. Naylor, chief inspector to the Ribble Joint Committee,

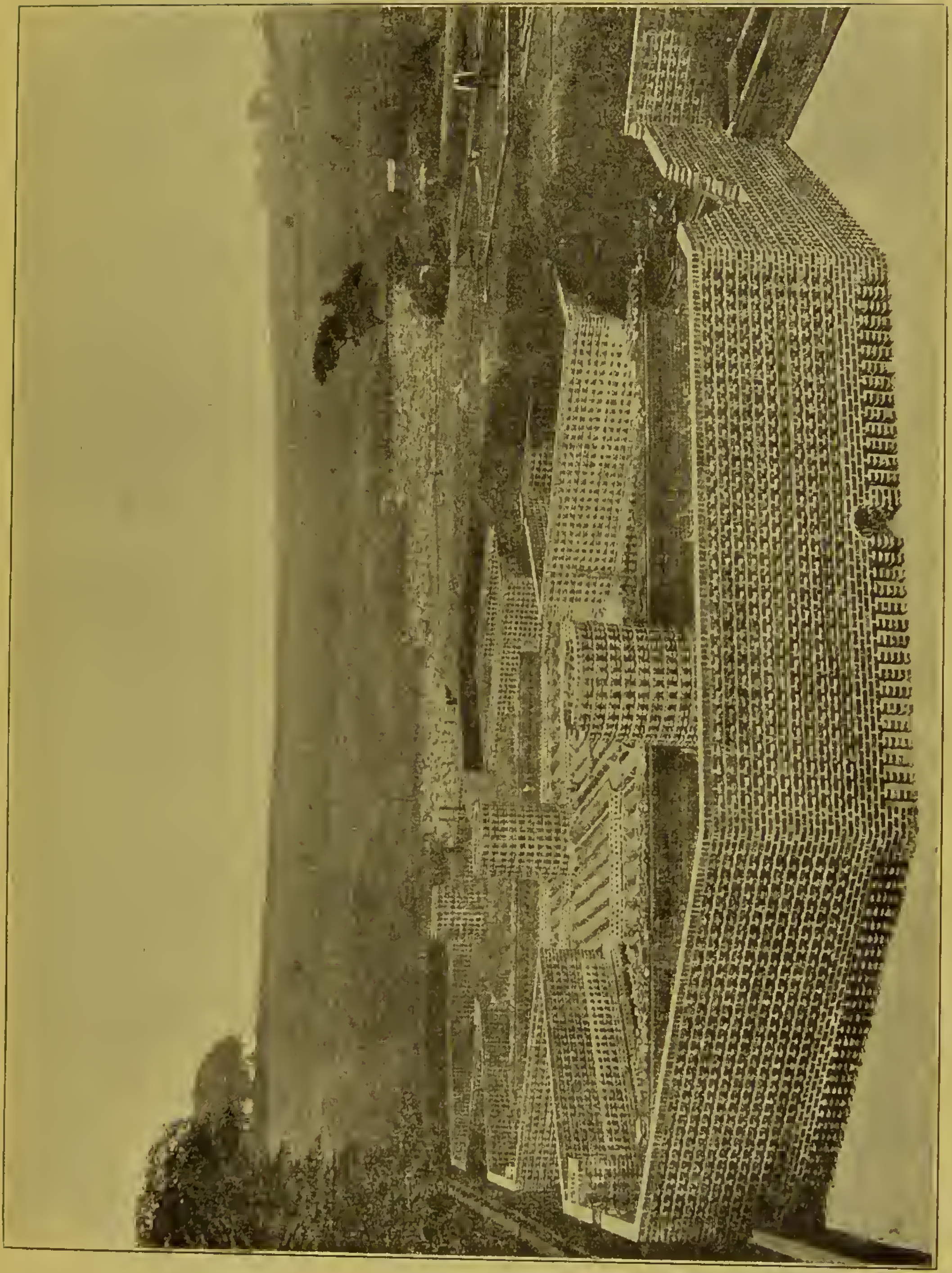

FIG. 27.—WHITTAKER-BRYANT THERMAL AEROBIC FILTERS

reporting on the experimental filters in January, 1899, says that the sewage is received in an ordinary precipitation tank and treated with 15 grains per gallon of lime, the sludge being allowed to remain in the tank and putrefy before passing to the filters, which contain 9ft. of 2½in. coke. An interesting point is that the tank effluent contained more organic nitrogen when the temperature was higher. His results are given in the following tables.

WHITTAKER-BRYANT FILTER.—QUANTITIES.

Sample.	Gallons passed on to Filter per hour.	Area of Filter, sq. yards.	Gallons per sq. yard per 24 hours.	Units of useful heat B.T.H.	Steam equivalent of utilized heat in lbs. total.	Coal equivalent of useful steam in cwts. per million gallons at 10lbs. water evaporated per lb. coal.
Jan. 25th, 1899 Raw Sewage	6,502	480	325	942848	832	45·6
Jan. 27th, 1900 Raw Sewage	5,909	480	295	3924070	3458	74·5

NOTE.—Each degree is equal to 885 lbs. of coal per million, heat radiated not included. Cost of coal per million—say, from 20/- to 30/-

ANALYSIS IN PARTS PER 100,000.

Sample.	Temperature F.	Albuminoid Ammonia.	Oxygen absorbed.		Nitrogen as Nitrates and Nitrites	Chlorine.	Solids.			
							Dissolved.		Suspended	
			3 mins.	4 hrs.			Mineral.	Volatile.	Mineral.	Volatile.
Jan. 25th, 1899										
Raw Sewage ...	45°.2 F.	1.06	2.32	10.4		12.0	53	32	22	30
Tank Effluent ..	51°.0 F.	·41	1.04	4.2		8.2	41	32	3	3
Filter Effluent ...	45°.6 F.	.160	.21	1.10	2.3	7·4	26	44	0	3
Jan. 27th, 1899										
Raw Sewage ...	43°.5 F.	1.92	3.1	16.3		12.5	50	36	19	30
Tank Effluent ...	53°.0 F.	·57	1.31	4·07		8.8	49	29	1	4
Filter Effluent ...	47°.7 F.	.160	.25	1.28	1.96	9.2	43	31	1	2
Filter Effluent freed from suspended matter		.08	.25	·94	1.98	9·3	44	30	...	...

He pronounces the effluent "fair" according to the Ribble standard, and found no putrefaction in five days at 80° F. The suspended matter in the final effluent contained 58·5% mineral and 41·5% organic; of the latter 23·2% was carbon, and 8·5% nitrogen.

He gives the cost of treatment as follows:—

Old Treatment—

	£	s.	d.
Precipitants, one ton of Lime and Copperas, or Alumina Ferric, per million gallons	2	10	0
Sludge, 40 tons per million, pressed to 8 tons dry, at 2/6	1	0	0
	3	10	0

New Treatment—

	£	s.	d.
Precipitants, one ton lime per million gallons ...	0	10	0
Sludge, 13 tons per million, pressed to, say, 2 tons dry (will now contain less water)	0	5	0
Coal, per million gallons	1	5	0
	2	0	0

> But, in conjunction with these figures, it is only fair to state that a good effluent was never obtained by the old method, although filters of considerable area were in use."

His later report at Accrington, in October and November, 1899, is not so favourable.

At the city of Reading, Pennsylvania, a very elaborate system of purification has been adopted, in which the action of light and strong aeration are prominent features, but preliminary screening, straining through coarse coke filters, and final "slow sand filtration by gravity" are also included. A detailed description is given in the *Public Health Engineer*, Jan. 13th, 1900.

Continuous Filtration.

The intermittent system recommended by the Rivers Pollution Commission of 1868, and enjoined by the second Royal Commission on Metropolitan Sewage Discharge in the words "the intermittency of applications is a *sine quâ non*," was almost universally adopted. But apart from the labour of regulation and supervision, another fault of the method was that the oscillations of functions between anaerobic and aerobic actions, involved in "resting full" and "resting empty" periods, created disturbance, and was detrimental to the consistent action of bacteria. In Ducat's and Whittaker-Bryant's filters, and formerly in Lowcock's the working was continuous, but rests at longer intervals were usually found necessary. Mr. Gilbert Whyatt* has called attention to the series of experiments commenced by Mr. Joseph Corbett, borough engineer of Salford, in 1893, and continued to 1898, on the basis of "a *continuous* passage of both sewage and air through the filter simultaneously." But the Corporation preferred that the experiments should be private, so no details or analyses were published. Of the filters constructed in 1893, two were of gravel and sand, two of coke-breeze, and two cinders, all being very good, but the latter the best.

The average analyses of the filtrates after 15 months continuous working showed a reduction to free ammonia, 0·829 and albuminoid 0·13, in parts per 100,000.

The principle of dividing into 3 or 4 heights of 20 inches thick with ventilating spaces between, was also tried, but "the advantage was just in favour" of the filter in one mass. Analyses of average samples from Oct., 1896 to April, 1897, show—

IN PARTS PER 100,000.

	O absorbed in 4 hours.	Free NH$_3$	Albuminoid
Divided filter	0·943	1·15	0·184
Filter in one mass ..	0·847	0·94	0·175

The distribution was effected at first by wooden troughs with holes, afterwards by spray jets with a head of 4ft. pressure, the amount delivered being 500 to 1,000 gallons per square yard. The chief requirement was that the filters should be thoroughly open.

The Salford Corporation

> "have decided to lay down a sufficient area of these filters to deal with the whole of the Salford sewage (12,000,000 gallons per day) at the rate of 500 gallons per square yard on a filter 5 feet deep; and although the Local Government Board have refused to sanction the scheme unless the Corporation include a sum to cover the purchase of land over which the filter effluent might be turned and further purified, they arranged to borrow £80,000 under section 35 of the Public Health Act, 1875, and to construct the works without the necessity for obtaining the sanction of the Local Government Board,"

Pub. Health Engineer, Feb. 3rd. 1900.

by inserting a clause to this effect in their Bill before Parliament in 1900.

It is important to notice that these "bacteria filters" are only dealing with an effluent already artificially purified by subsidence, straining and precipitation. Thus, to quote the Report :—

> "These bacteria filters were protected by a roughing filter of fine gravel, its purpose being to arrest any floating fats or any precipitated sludge which might find its way through the subsidence tanks. This roughing filter required to be cleaned every one or two days. . . . . . The Salford process will then be three-fold : first, *precipitation by the lime or other chemical process ; second, clarification and interception of all suspended matters by roughing filters of coarse gravel ; third, purification by means of bacterial filters on the lines above described.*"

The expenses and sludge of the older processes are thus retained.

> "The new works will therefore consist of the necessary roughing filters, the extension of the lime-mixing house, and construction of the large area of aerating filters just mentioned, together with the erection of cinder-crushing house, etc. These new works were commenced in the autumn of 1898, and will, probably, be nearing completion by the summer of 1900."

According to Mr. Corbett, the works are designed for pumping and fully treating per day 30 million gallons for two or three days together, or about 20 million gallons for some weeks, the ordinary flow being 11 to 12 millions, from a population of 210,000, with a water supply of 4½-5 million gallons, or 25 gallons per head. "The balance, therefore, of half the ordinary sewage is subsoil water, and the sewage requires about 4 grains of oxygen per gallon to oxidize the putrescible matter per gallon on arrival at the works."

In 1893, Mr. Wallis Stoddart published some experiments[*] on small model filters of coarse chalk, with arrangements for continuous dropping and trickling. He seeded the bed with liquids containing ammonifying, nitrosifying, and nitrifying organisms successively, and obtained different results according to the rate of flow. The organisms were too much mixed in the same area : he secured, however, "a very constant formation of nitrate of lime," and with a polluted well water he records the following purification :—

---

[*] *Practitioner*, 1893; *Analyst*, 1894, p. 19.

	Original Water.	Filtered Water.	
		Single rate	Double rate
Ammonia free	·252	·0003	none
,, albuminoid ..	·018	·0023	·0056
N as Nitrite and Nitrate ...	4·61	5·77	5·48
Nitrites	abundant	none	none
Solids	112·0	106·0	107·0
Chlorine	8·8	8·8	8·9
Oxygen absorbed :			
15 minutes	·084	...	·034
4 hours	·112	...	·059
Colour	deep yellow-brown	...	yellow-green

With a sewage percolating continuously through 5ft. of coarse chalk with an upward current of air, the results were :—

	Sewage.	Effluent.
Free Ammonia	3·85 ...	·0013
Albuminoid	·175 ...	·0158
Nitrogen as Nitrates	none ...	5·99
Nitrites	none ...	none
Chlorine	7·9 ...	7·8
Oxygen absorbed 15 min ...	·566 ...	·066
,, ,, 4 hours ...	1·22 ...	·132
Dissolved solids	51·0 ...	79·0

The flow on the model filter was calculated as equivalent to 200 gallons per square yard per day.

A model of this experimental filter was exhibited at a meeting of the British Medical Association at Bristol, in 1894, but the first successful working filter on this plan was erected at Horfield, near Bristol, in September 1899, and has since been running continuously night and day. The composition of the filtering material is immaterial, so long as it is insoluble and not too friable ; the size should be 1½ to ¾in., in no case less than ½in., and the depth 6 feet. A principal feature is the distributor with points, described in Chapter XII.

The nitrogen as nitrates and nitrites in samples of the Horfield filtrates is given as 2·14, 2·57, and 1·81 parts per 100,000. A recent analysis of the filtrate shows that the oxidation is not complete when the flow is increased :—Saline ammonia, 1·90 ; albuminoid, 0·12 ; oxidized nitrogen, 2·80 ; oxygen absorbed, 0·88 ; chlorine, 6·14 ; parts per 100,000. With this filter using the distributor devised by him and with a precipitated sewage or hydrolysed effluent of weak character, the rate of continuous flow can be increased up to 1,000 or 1,200 gallons per square yard per day and still yield a final filtrate which is non-putrescible with an appreciable amount of nitrates and dissolved free oxygen. With stronger sewages, of course, this rate would be considerably diminished, but the fact remains that continuous filters of this type and as used by Moncrieff are capable of dealing with the sewage at a much greater rate than intermittent ones when a well-devised distributor is used for ensuring that the whole of the filter bed is utilised.

Mr. Stoddart points out that "the improved filter does not constitute a complete system of sewage disposal, as it is not intended to deal with crude sewage."

Repeating the three stages of natural sewage purification—

(1) *Anaerobic*—hydrolytic solution and ammoniacal change.
(2) *Partially aerobic*—nitrites and simplified bodies.
(3) *Complete oxidation and nitrification.*

it is obvious that a certain preparation is necessary before a sewage liquid can take advantage of an excess of oxygen. Consequently in all systems professing to depend entirely on oxidation we notice that some preliminary treatment, whether natural or artificial, has occurred, and the solids have been avoided by screening, straining, sedimentation, or precipitation, before the continuous and free aeration has been useful in the third stage.

CHAPTER XI.

BACTERIAL PURIFICATION *(continued)* — Unaided Bacterial Processes — Scott-Moncrieff's Tank—Conditions of Hydrolysis—The Exeter Septic Tank—Barrhead Works—Moncrieff's Trays—Comparative Nitration by Different Systems—Oxygen Relations—Separate Zones—Caterham—Manchester Experiments.

WE next come to processes that rely for purification on the natural action of bacteria without extraneous aid. This idea had been indicated in the "Automatic Scavenger" of Mouras which we have already described, and could also be gathered from the Massachusetts investigations, but prior to the latter, in 1890, Scott-Moncrieff made a number of experiments with regard to the observed rapid liquefaction of organic matter in sewers. If this action, which was now known to be due to liquefying bacteria, could be intensified and regularly conducted within a small area, it promised to eliminate the sludge difficulty.

It had long been known that in the slow filtration of sewage, more particularly when the direction was upwards, so that little or no mixing with air occurred, very considerable changes in the organic matter were brought about, entirely unconnected with oxidation. Thus in one of Frankland's experiments, as early as 1870, when a strong London sewage was made to traverse, "continuously upwards so as to exclude aeration," a layer of sand, the analysis of sewage and effluent given is the more instructive as the meaning of it was not understood at the time.

PARTS PER 100,000.

	Crude sewage.	Effluent.
Solid matters in solution	64·5	80·5
Organic carbon	4·39	3·23
Organic N	2·5	1·4
NH_3	5·5	4·6
N as nitrates and nitrites	None	·328
Total combined nitrogen	7·0	5·5

That is to say, the anaerobic bacteria have acted in the usual way:—

1. They have dissolved 16 parts per 100,000 of the solid matters or sludge, thereby increasing the solids in solution from 64 to 80.

2. Some of the ammonia has been changed into, almost certainly, *nitrite.*

3. 1·16 parts of carbon (25 per cent.) and 1·1 parts of nitrogen (44 per cent.) have been eliminated as non-ammoniacal gases, methane, N., and nitrogen oxides, with probably some CO_2.

Mr. Moncrieff began on a practical scale in 1891 by constructing at Ashtead a bacterial tank into which the crude sewage was admitted from below and gradually passed upwards over the surfaces of a bed of stones. He found that the liquefaction of the solids was so effective that the whole sludge of seven years from a household of ten persons was absorbed on nine square yards of land, causing no distinction in appearance between this soil and that surrounding. The space beneath the under-grating of the tank had a capacity of less than five cubic feet, and would obviously have filled up in a short time but for the liquefying action that had taken place.

In 1892 his process was examined by Dr. Houston and later by Dr. Sims Woodhead and myself. Dr. Houston's report of 1893 is practically the first literature on the purification of sewage as a whole bacteriologically, without deposition or chemicals and with hydrolysis by micro-organisms of the grosser organic matter as a prelude to further treatment, a point which is not mentioned in the Massachusetts reports.

In this way the difficulty of the production of sludge could be completely avoided. I have shown how a great part of this, during or after liquefaction, disappears as gases. It is obvious, however, that the remaining liquid will retain the ammonia which has been produced by the hydrolysis, together with residues of nitrogenous and carbonaceous dissolved matters, so that judged by ordinary standards of analysis, this liquid, in the first stage, will show somewhat large amounts of carbon and nitrogen. As examples of some effluents from Moncrieff's anaerobic tanks, derived from heavy domestic sewages during the early stages of experiments, I may quote the following analyses made by C. G. Groves for the Thames Conservancy, and by myself:—

PARTS PER 100,000.

Date.	Analyst	Suspended Matter.	Dissolved solids.	Cl.	Ammonia.	Albuminoid NH_3	Oxygen consumed
May 7th, 1895	Groves.	Trace	101·0	10·4	15·0	0·8	5·4
June 1896	Groves.	,,	112·0	21·0	7·0	0·8	3·9
July 1897	Rideal.	,,	191·5	59·4	9·0	0·7	8·2

With reference to the first sample, Groves remarks that it contains *a large amount of easily-decomposable nitrogenous organic matter in solution.* This great instability of the organic compounds that come over from cultivation tanks is the principal feature of the process.

With the object of obtaining an oxidized effluent, Moncrieff then duplicated the tanks and used them alternately with periods of aeration and rest. The effluent obtained was clearer, and had less odour, but showed practically no nitrification. That the liquid was ready for natural oxidation was shown by the fact that when at Towcester in 1893, the effluent was passed into a small brook, the water actually became clearer below the discharge than above it. Efforts were then directed towards carrying on this final change within the apparatus. It was first tried to obtain nitrification by passing the effluent through "nitrifying channels," consisting of half drain pipes joined in line by cement, and filled with coke. But the result was not commensurate, for the reason that the right organisms were not developed. During the transit, the liquid was largely exposed to the light, whereas it is known that the bacteria forming nitrates thrive best in the dark. It was noticed that denitrifying organisms, which are not so sensitive, had actually in some cases reduced existing nitrates, as pointed out by Dr. Houston in the Ashtead experiments. How the difficulty was afterwards overcome by the construction of the nitrifying trays will be described later.

Up to this point there was still a belief that hydrolysis and aerobic nitrification could be carried on successfully in the same tank. At Aylesbury, air was forced in by a steam jet, with this object in view, but the result was unsatisfactory.

It became evident that the nitrogenous organic matter must be as far as possible broken up into ammonia before being oxidised to nitrates, and that these two reactions should be carried on in separate areas, the one under anaerobic conditions, and the second with free admission of air but not of light, when the distinctly nitrifying bacteria should be free to work under the most favourable conditions. Even in very strong sewages there seems almost no limit to the capacity of the hydrolytic ferments to break down nitrogenous matter into ammonia. Thus Marchal found that one of the organisms that effects this function, *B. mycoides*, could thrive in a medium containing two parts in a thousand of caustic potash, equivalent to 660 parts per 100,000 of free ammonia, and in septic effluents in the first stage I have found as much as 30 to 40 parts per 100,000 of NH_3.

But it was found, on the other hand, that there was a limit to the amount of anaerobic change if nitrification in the further stage is to be carried to a successful issue. As already mentioned (p. 97), the prejudicial influence of ammonia on the nitrifying bacteria was pointed out by Warington, in 1891. Winogradsky and Omeliansky* have recently investigated this retarding action of different substances, and have found that :

1. Sodium carbonate is essential for the growth of both nitrous and nitric organisms. There would always be sufficient in sewage from the presence of washing soda, also from the action of ammonium carbonate on the sodium chloride of urine.

2. Various organic infusions, such as hay, peptone, sugar, broth, etc., had little effect, or were even favourable, except in amounts unlikely to be present in sewage.

3. Urea was without effect when the amount is only 0·05%, but 0·5 to 0·8% hinders nitrification. Addition of 2% of urine resulted in the time required for oxidation being increased five times, and this result is due to the large excess of ammonia.

4. Iron salts seemed to assist the nitrification.

In experiments by the Moncrieff process at Caterham dealing with a heavy sewage containing 18 parts of Cl. per 100,000—the entire discharge from the barracks—the preliminary process was pushed much further than usual, to try if it were possible to carry the anaerobic fermentation too far, with the object of ascertaining the most favourable point, by estimating the free ammonia, and finding what amount gave the best results in nitric nitrogen. Exceptionally anaerobic conditions were introduced, by means of inverted open-mouthed glazed earthen vessels, about 400 in number, piled in a tank 20ft. by 10ft. by 9ft. deep, and kept down by weights. Each pot became filled with gases of the character I have described, devoid of oxygen, so that there were a large number of surfaces on which zooglæa colonies of bacteria could quietly develop in contact with the percolating sewage. The result was an effluent containing 126 parts per 100,000 of dissolved solids, 35 of free NH_3, and 5·3 of organic nitrogen. The liquid was now highly toxic to any but anaerobic organisms, and absolutely refused to nitrify. When diluted, however, with a few volumes of natural water it rapidly became purified.

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* *Chem. Centralblatt, 1899*, ii., 132, 217, and 264.

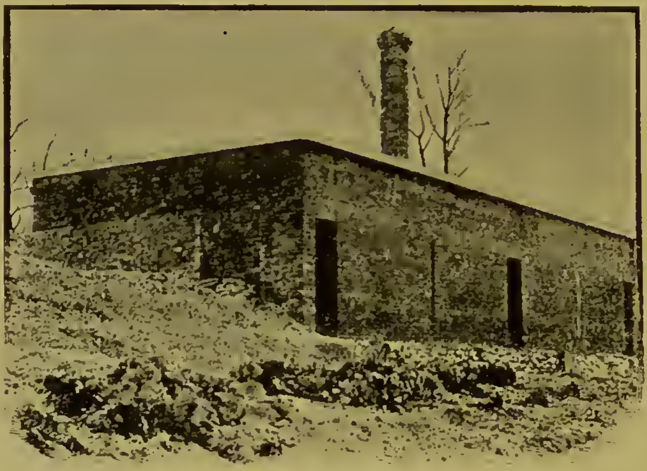


FIG 28. FILTER HOUSE AT CATERHAM.

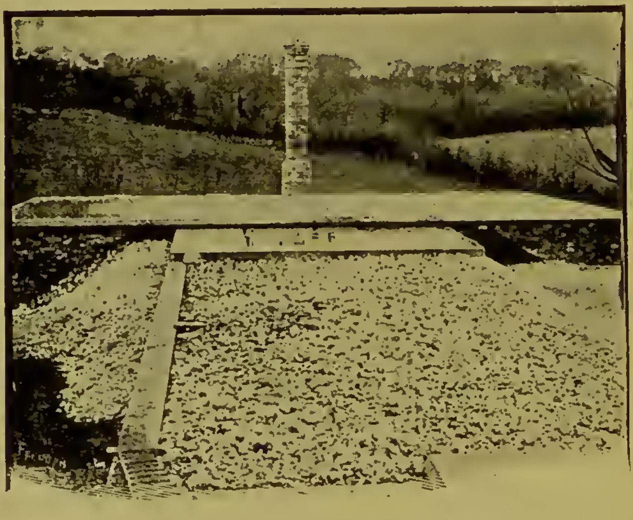


FIG 29. CATERHAM WORKS, MONCRIEFF SYSTEM.

The anaerobic cultivation tank is therefore an essential preliminary, and is used by Mr. Moncrieff in all his installations. The work done in it is equivalent to that which takes place in the septic tank, about to be described, but it differs from it in design. Both processes obviate the sludge difficulty of the older precipitation method, and also the choking up of the open downward contact beds advocated by Mr. Dibdin. Drs. Kenwood and Butler point out that an upward cultivation filter or tank has advantages over a septic tank in which there are no surfaces provided for the organisms. They say, " while upward filtration offers a better prospect of effecting the separation and solution of the suspended matters of sewage, it, at the same time, reduces the pollution of the effluent better than any system which aims at their removal by digestion in a hollow chamber, such as the septic tank." Cultivation tanks on these lines are in course of construction at Finchley.

In 1895, Mr. Cameron, City Surveyor of Exeter, introduced his " septic tank " process for the treatment of a portion of the sewage of the city, comprising about 1,500 to 2,000 persons, on the combined system, with a volume of approximately 50,000 gallons. The tank is cemented watertight, and banked below the ground to keep it from changes of temperature, the top being arched over and covered with turf, so that light and air are excluded. The raw sewage, without screening or any preliminary treatment, enters by two inlets, which are carried down 5ft. below the surface, in order that the entry may be quiet, so as not to disturb the bacterial layers, also that air may not be carried in, nor any gases escape back to the sewer. After passing through a "grit chamber," 10ft. deep by 7ft. long, and of the same width as the tank (18ft.), the sewage flows over a wall submerged one foot below the surface into the main portion of the tank, which is 56ft.10in. in length, 7ft.6in. in depth, and 18ft. wide, its capacity up to the level of the liquid being 53,800 gallons, or approximately a day's supply. Hence the transit of the sewage is ordinarily very gradual, averaging about 24 hours in the tank, so as to give ample time and quiet for the changes.

In this way the sewage becomes mixed and averaged, and the bacteria have a chance of working during the passing through the 65ft. length of flow, which the sewage traverses at the rate of a little more than two feet per hour. No obstruction is present, and the entire space is available, differing from what we have seen of tanks partially filled with stones or coke. In the latter the dimensions must either be larger in proportion, or the sewage must pass at a greater rate, the bacteria also are not so freely distributed through the liquid. From the inspection chamber it is seen that a leathery scum from two to six inches thick, according to the position, collects on the surface and renders the whole anaerobic. Below this is a zone of fermentation, in which the sewage is mainly clear, but bubbles of gas keep the liquid in a state of quiet admixture. At the bottom of the tank there is a layer of the dark peaty matter previously referred to (p. 81), which is so small in amount that during a period of a year's working, it does not require to be removed. It is reported since, that after three years without clearing, the amount of sediment or residue from the sewage and excreta of a population of 1500 was under 4ft. deep. The insoluble organic matter has been gradually broken up by the bacteria, while the inorganic substances have been kept in suspension by the gases and have passed off in the flow, so that the quantity does not sensibly increase. I found this peaty deposit to contain about 68 per cent. of mineral, 32 per cent. of organic matter, and 2·4 per cent. of nitrogen. We have seen in Chapter V. (p. 96) that humous matter is favourable and even necessary for subsequent nitrification.

The flow through the tank is continuous, therefore requires no attention for Sundays or at night. The submergence of inlet and outlet minimises the disturbance of the contents. At the far end of the tank, a transverse iron pipe, about a foot below the level of the liquid, with a slot on the under surface extending its length, forms an exit for the effluent, which passes into a small cistern with a V-gauge, and then falls in a thin stream over an aerating weir, with a view to restore aerobic conditions. It then flows through distributing channels on to filters of coke breeze or clinker, similar to those at Barking and Sutton, four of which are used at a time, and one kept in reserve. An automatic gear devised by Mr. Cameron regulates the cycles of filling, resting full, emptying, and aeration, so that here again no attention is required. The Local Government Board inquiry of 1897 approved of the system being applied to the whole of the city, of a population of 46,000, with the usual proviso as to land. The daily flow is 1,064,610 gallons, and for this, six tanks 181ft. by 35ft. by 7ft. deep, with a capacity of 262,422 cubic feet, will be provided, in which the suspended solids will dissolve. Eight filters, of a total area of 2½ acres or 13,600 square feet, each having a depth of 3½ft. of crushed furnace clinker on 6in. of coarse gravel, and a working capacity of 2½ million gallons a day, operating with the alternating gear as before, will deal with the tank effluent.

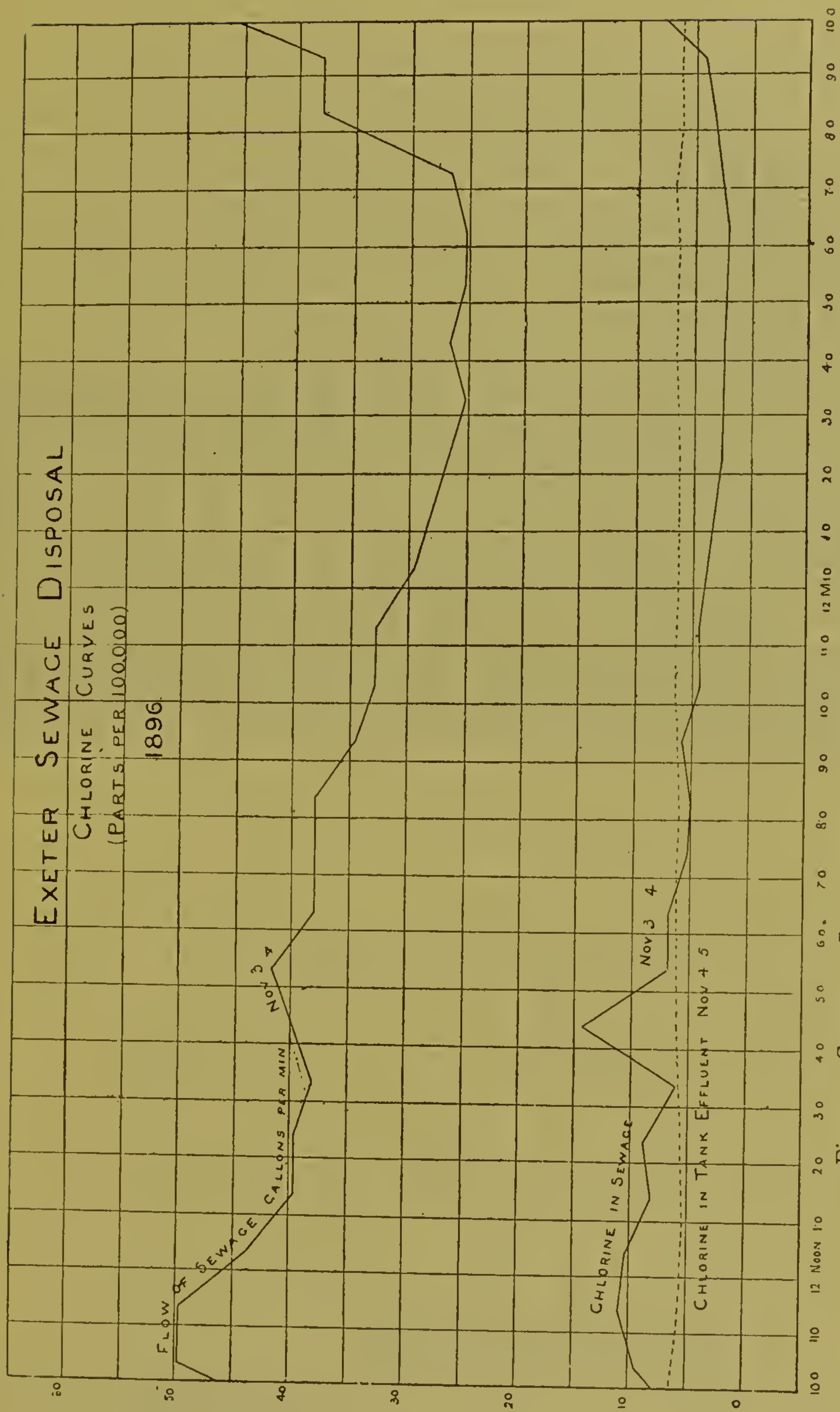


Fig. 30.—Chlorine Curves showing smoothing effect of Septic Tank (Perkin).

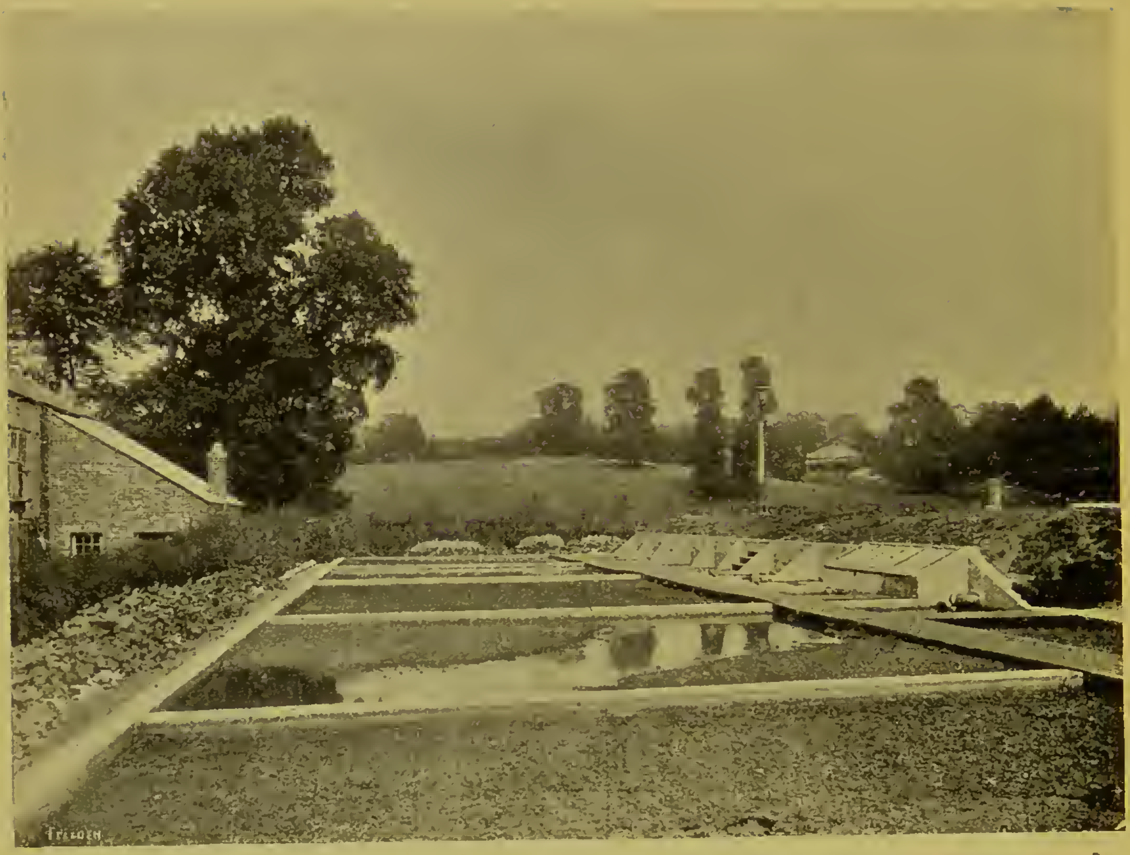


Fig. 31.—Experimental Septic Tank and Filters, Belle Isle, Exeter.

Diagram of Overflow Pipes.

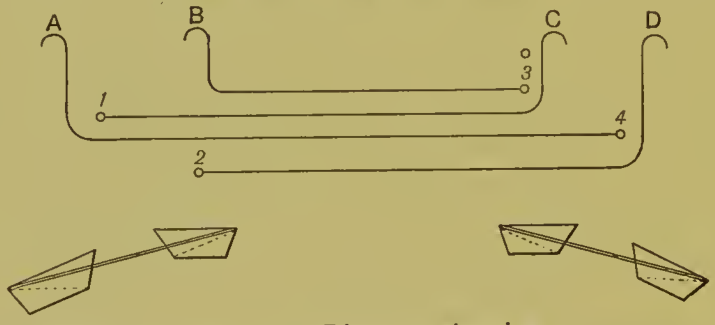
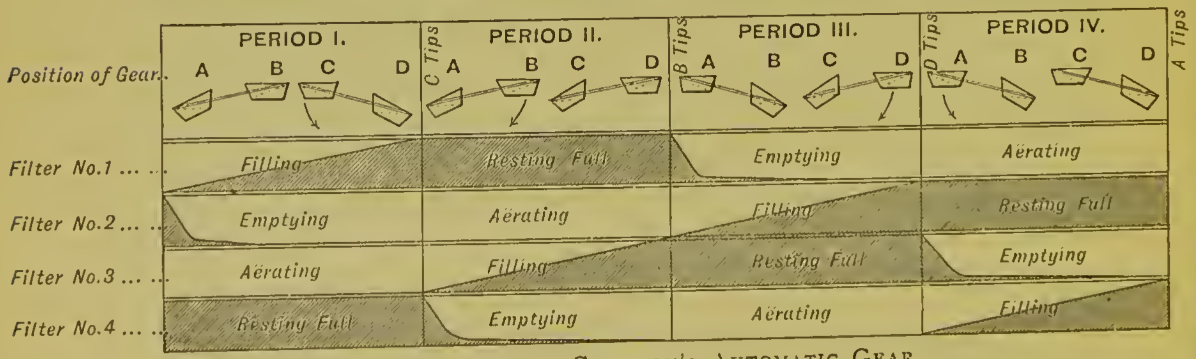


Diagram showing
successive states of Filters corresponding to successive positions of alternating gear:-


Position of Gear.
A
B
C
D
C Tips
B Tips
D Tips
A Tips

	PERIOD I.	PERIOD II.	PERIOD III.	PERIOD IV.
Filter No.1 ...	Filling	Resting Full	Emptying	Aërating
Filter No.2 ...	Emptying	Aërating	Filling	Resting Full
Filter No.3 ...	Aërating	Filling	Resting Full	Emptying
Filter No.4 ...	Resting Full	Emptying	Aërating	Filling

Fig. 32.—Working of Cameron's Automatic Gear.

It will be seen that Mr. Cameron, like Mr. Scott-Moncrieff, carefully differentiates between the hydrolytic or solution process, and the subsequent oxidation required for final purification. Dr. Sims Woodhead has shown that while the anaerobic organisms are more numerous in the tank, a number of liquefying aerobic organisms are still present, and increase on passing over the aerating weir. The filters are, of course, intended for aerobic working, but are open to the objections already urged against intermittent filters.

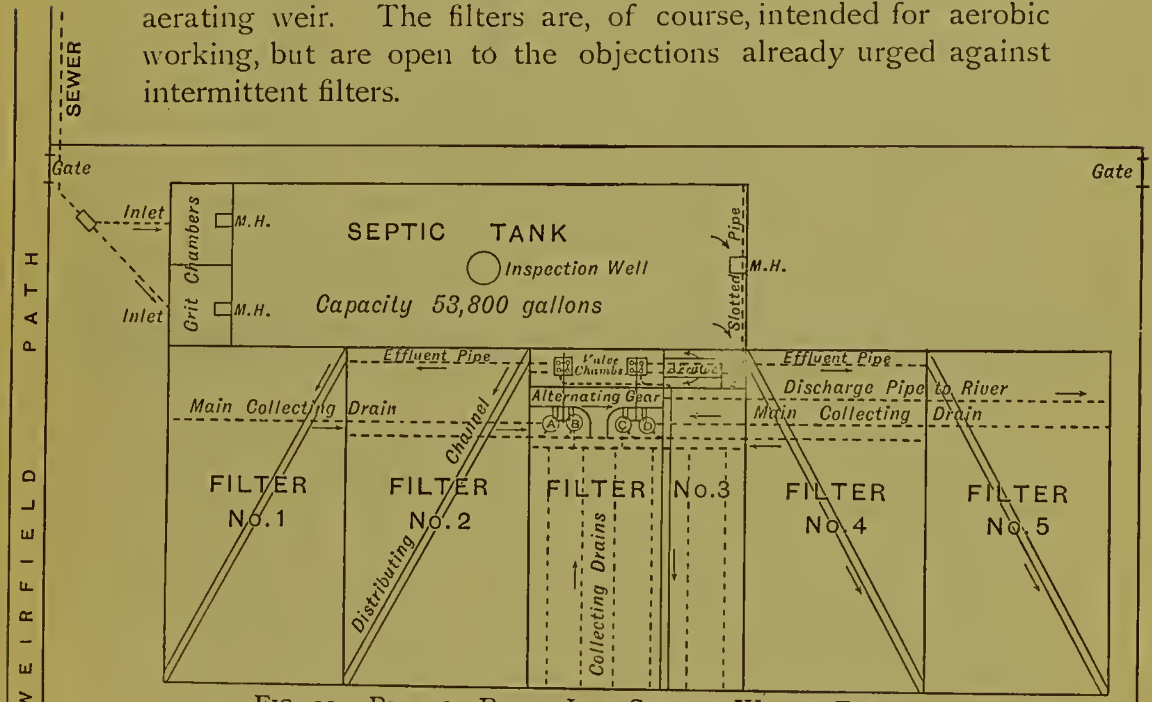

SEWER
WEIRFIELD PATH
Gate
Gate
Inlet
Inlet
Grit Chambers
M.H.
M.H.
M.H.
SEPTIC TANK
Inspection Well
Capacity 53,800 gallons
Slotted Pipe
Effluent Pipe
Effluent Pipe
Valve Chamber
Alternating Gear
Main Collecting Drain
Channel
Distributing
Collecting Drains
Discharge Pipe to River
Main Collecting Drain
FILTER No. 1
FILTER No. 2
FILTER No. 3
FILTER No. 4
FILTER No. 5

FIG. 33.—PLAN OF BELLE ISLE SEWAGE WORKS, EXETER.

The changes occurring in the tank are rather complex. Analyses were made by myself, and by Dupré and Perkins, in 1896 and at subsequent dates, and by Dibdin and Thudichum, and Pearman and Moor, in 1897. From these it appears that the total dissolved solids are increased somewhat, but not in relation to the organic *débris* that has passed into solution. A large proportion has undergone the hydrolytic decomposition which we may represent in two forms :—

1. Producing nitrogen, methane, a small quantity of hydrogen and carbonic acid, as in the typical equation already given :—

$$4C_8H_{13}N_2O_3 + 14H_2 = 4N_2 + 19CH_4 + 13CO_2 + 2H_2$$

2. Producing, ammonia, CO_2, and a large quantity of H :—

$$2C_8H_{13}N_2O_3 + 16H_2O = 4NH_3 + 16CO_2 + 33H_2$$

These reactions go on simultaneously, along with others, according to the species of bacteria present. The result is the

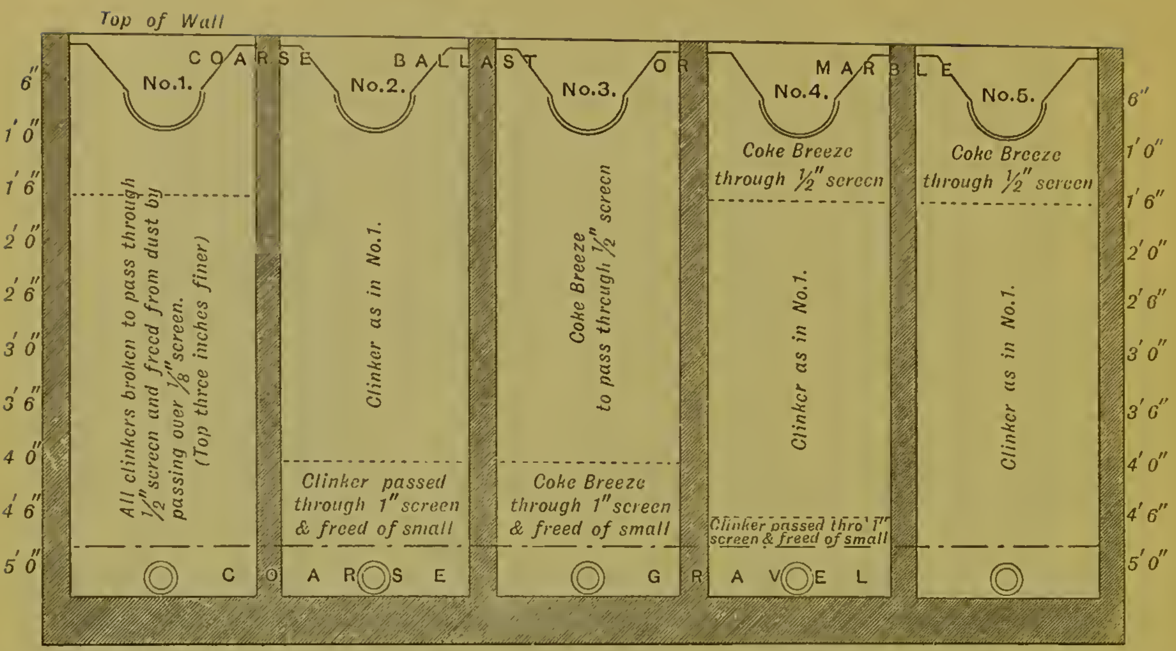

Top of Wall
6"
1' 0"
1' 6"
2' 0"
2' 6"
3' 0"
3' 6"
4' 0"
4' 6"
5' 0"
C O A R S E B A L L A S T O R M A R B L E
No.1.
No.2.
No.3.
No.4.
No.5.
All clinkers broken to pass through ½" screen and freed from dust by passing over ⅛" screen. (Top three inches finer)
Clinker as in No.1.
Clinker passed through 1" screen & freed of small
Coke Breeze to pass through ½" screen
Coke Breeze through 1" screen & freed of small
Coke Breeze through ½" screen
Clinker as in No.1.
Clinker passed thro' 1" screen & freed of small
Coke Breeze through ½" screen
Clinker as in No.1.
C O A R S E G R A V E L

FIG. 34.—SECTION OF FINE BEDS, EXETER.

production of a large quantity of inflammable gas, which according to Clark amounts to half a cubic foot per 100 gallons of sewage, and as previously mentioned, has been successfully utilized.

The ammonia and the major part of the CO_2 remain in the solution, which contains on an average 33 per cent. more of free NH_3, 29 per cent. less of organic matter as measured by the oxygen consumed, and 46 per cent. less of albuminoid ammonia. The organic matter is now in a readily oxidizable state, and passes on to the second or aerobic stage, in which it is dealt with by the filters. A large amount of carbonic acid is produced in the filters by oxidation of the organic matter, and is driven out in the stages of filling. The residue of the nitrogenous matter is changed into nitrates averaging about one part of nitric nitrogen per 100,000.

The following table shows the per-centage purification produced by the Exeter process, as stated by different observers at the inquiry in 1897, measured by the reduction of albuminoid ammonia and of the oxygen consumed :—

	Albuminoid NH_3	Oxygen consumed.
Dupré	84.9	88.3
Perkins	64.4	78.7
Dibdin and Thudichum	63.2	80.9
Pearmain and Moor	80.0	90.0
Mean	73.6	84.0

My own figures for the separate stages of purification per cent., published in 1896, were as follows :—

	Albuminoid NH_3	Oxygen consumed.
By tank ...	46	29
By filters	31	53
Total ...	77	82

The installations at Yeovil and other places have proved that the septic tank process is not affected by manufacturing refuse. The smoothing and diluent effect in the volume of sewage, and the room for precipitation and neutralization by the ammonia, seem to obviate these difficulties.

Three other points in the Exeter Local Government Board Inquiry require comment. One was the action of the grit chamber. On entering this the heavy particles of gravel and sand at once sank, while the organic refuse, which in fresh sewage always floats, passed over the submerged wall into the tank. The result is that no solid sewage remains in the grit chambers, and the gravel may at intervals be dredged out without disturbing the contents of the tank. This is not at all parallel to the action of screens or straining filters, which also arrest the solid organic matters, thereby forming a subsidiary sludge.

The second point is as to the stay in the tank. The flow of the liquid through the tank in dry weather occupies 24 hours or more, and in wet weather may be reduced to 7 hours. During that time, it is, as we have seen, profoundly altered by the action of the anaerobic bacteria But the more intractable portions of the solid matter remain much longer : they are entangled by the active zooglæa scum on the surface, or may slowly sink to the bottom : and accumulate in the tank until the rate of dissolution is equal to the accretion of the fresh solids. When equilibrium is established, the scum and the sediment, though showing some fluctuation, should have an approximately constant volume.

The third point, the possible survival of pathogenic organisms, has been dealt with in Chapter IV.

At Barrhead, near Glasgow, works on the septic tank system have been constructed, designed for a population of 10,000, and a maximum flow of sewage and storm water of 400,000 gallons per day, with provision for dealing with much larger exceptional quantities. There are two grit chambers, four septic tanks, and eight aerating bacterial filters, the whole built in concrete. Each of the tanks is 100ft. long by 18ft. wide and 7ft. deep at low water,

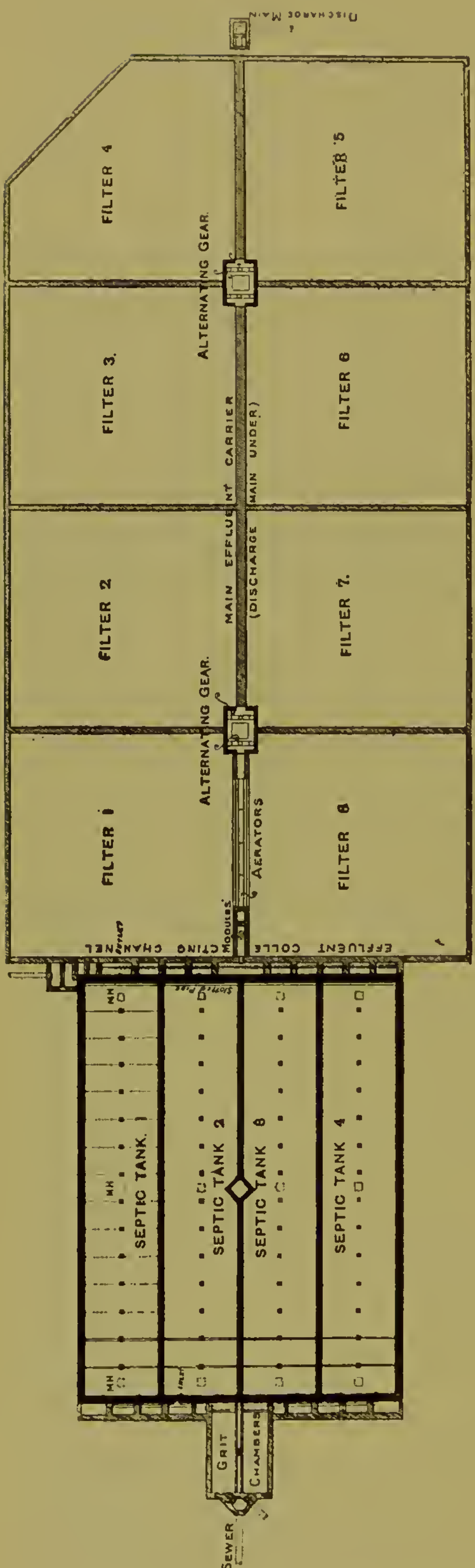

DISCHARGE MAIN
FILTER 4
FILTER 5
ALTERNATING GEAR.
FILTER 3.
FILTER 6
MAIN EFFLUENT CARRIER
(DISCHARGE MAIN UNDER.)
FILTER 2
FILTER 7.
ALTERNATING GEAR.
FILTER 1
AERATORS
FILTER 8
MODULES
EFFLUENT COLLECTING CHANNEL
SEPTIC TANK 1
SEPTIC TANK 2
SEPTIC TANK 3
SEPTIC TANK 4
GRIT
CHAMBERS
SEWER

Fig. 35. Barrhead Installation.

roofed by concrete arches on rolled steel joists with brick piers.

The dry-weather capacity of the four is 312,500 gallons, but in periods of storm allowance is made for a rise of 18 inches, or an additional capacity of 70,000 gallons, the flow to the filters being maintained constant by two controlling modules. Each filter is 55ft. by 54ft. in area, with 4ft. depth of broken furnace clinker; total filtering area 2,540 square yards (fig. 35). Two of the eight filters are usually kept in reserve. The practical working is the same as that at Exeter, and is thus described :—

> "The tank effluent is supplied to one filter at a time, and is distributed over the surface of the filtering material by a system of stoneware distributing channels laid thereon. The discharge valve is closed meanwhile, so that the interstices of the filtering material become filled with the tank effluent. The effluent remains in the filters for about one hour and a half, during which the dissolved impurities are oxidized by the bacteria attached to the filtering medium. The discharge valve is then opened, when the filtered effluent escapes, drawing down after it a supply of air into

> every crevice of the filter. The latter is then left to drain and aerate while the other working filters are filled in turn, after which it is again filled. This method of working renders the filters self-cleansing, so that they retain their purifying power unimpaired. The opening and closing of the admission and discharge valves are automatically effected by the overflow of a small quantity of filtered effluent. These operations, therefore, go on continuously without the intervention of manual labour."

One very important feature of the septic tank from an engineering point of view, is the fact that the sewage enters and emerges at practically the same level, so that no pumping is required, nor difference of level necessary in the land, for the first part of the process, such as we have seen in the "bacteria bed" terraces at Hampton and elsewhere.

In common with other bacterial processes, a certain time is required after a new installation for the bacteria to attain full activity, but on account of the absence of interruption this would appear to be short, especially if inoculated with scum from an old active tank, after which the process goes on automatically.

Some late improvements in the septic tank (patent 5671, 1898,)

> "have for object to provide in a small space a considerable area of floor to receive deposited matter, whereby the separation of the solid matter from the sewage is facilitated, and the deposited matter is subjected to the washing action of the sewage. Means whereby gas generated in tanks or receptacles by the decomposition of sewage or other organic matter, may be conveniently drawn off for use when required; means for filling and emptying tanks, filters and other receptacles. The first is effected by constructing the tanks with two or more decks or floors over which the sewage is caused to pass. Depressions or pockets may be provided at the ends of the spaces between the decks or in the lower floor of the tank, into which the deposited matter may drift and from which it may be removed, without emptying the tank. The second is effected by constructing two or more outlets in a tank in which gas is generated from sewage or other organic matter, opening at different levels. The lower ones may be closed so as to force the liquid to rise to a higher level and so create a pressure in the tank by which the gas may be expelled. The third is effected by suspending the actuating buckets from the levers carrying the valves of the filters described in specification 3,003 of 1896."

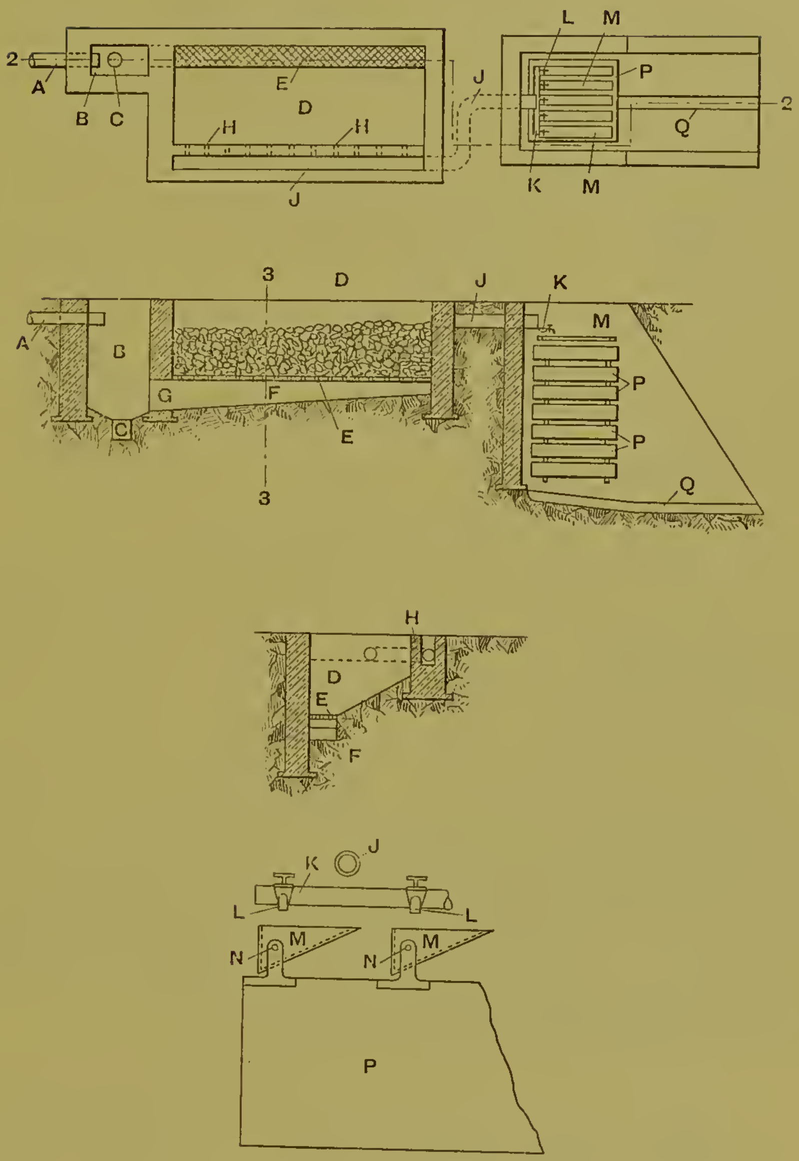
It has been already pointed out how in ordinary bacteria beds the natural reactions are somewhat fortuitously reversed and confused, according to the periods of filling or rest, the fault being caused by mixing all the different bacteria in one or two large filters.

By using a series of smaller, separate areas, and passing the effluent continuously and progressively through them, with ample opportunity for the access of the air where it is required, the organisms gradually choose their own conditions, and allied groups gather together at different levels as coatings on the filtering material. The advantage of separating the organisms appeared early from a remark of Jordan and Richards, in the Massachusetts Report of 1890 (ii, 877), that "in the filter tanks at the Lawrence Experiment Station, speedy nitrification was always coincident with a marked decline in the numbers of bacteria. The more complete the nitrification, the fewer were the bacteria in the effluent." In the latter sections the nitrifying organisms should be almost alone, and therefore able to exert their full activity. In this way Mr. Moncrieff has secured a much higher nitrification than has been obtained by the other processes.

This he has accomplished by spreading the "tank effluent" by tipping troughs or distributors over the uppermost of a series of "nitrifying trays." (See fig. 36.) In experiments at Ashtead with a domestic sewage, nine perforated trays containing coke, were supported vertically over one another at about three inches apart. Each tray had an effective area of one square foot, and contained seven inches of coke, broken to one inch in diameter. It required only from eight to ten minutes for the liquid to pass through all the trays. (Chapter XII). In 1898, after the apparatus had been running continuously for three months, I collected on two occasions samples from the different trays and examined them separately. The rate of flow was approximately measured as follows :—

	Flow observed. Per sq. foot.	Equal to gallons per acre per 24 hours.
January 25th, 1898	1 litre in 15 minutes.	884,600
February 8th, 1898	1,140 cc. in 12 minutes.	1,253,400
Mean ...		1,071,500

The results of these analyses of the tank effluent and final filtrate from the ninth tray are given in the table (p. 224):—


L
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L
L
N
M
N
M
P

Fig. 36.—Section of Scott-Moncrieff Cultivation Bed and Bacteria Filters

PARTS PER 100,000.

	I.		II.		III.	
	0	9	0	9	0	9
Chlorine...	9·0	7·5	6·3	6·4	5·5	5·5
Ammonia	11·5	0·25	4·25	0·755	4·0	0·42
Albuminoid ammonia ...	1·5	0·60	2·93	0·475	1·472	0·107
Nitric nitrogen	0·12	9·0	none	5·98	none	4·34
Nitrous nitrogen ...	none	sl't trace	none	0·06	none	0·034
Total unoxidised N ...	12·35	0·60	6·60	1·12	5·35	0·148
Organic N	2·05	0.394	3·10	0·50	2·06	0·113
Total nitrogen	12·47	2·60	6·60	7·16	5·35	4·522
Oxygen consumed ...	9·84	0·589	9·05	0·608	7.52	0·632

PER-CENTAGE PURIFICATION.

	I.	II.	III	Average.
(1) Oxygen consumed...	94	93·3	91·6	93
(2) Oxidation of nitrogen	93·7	84·3	96·7	91·6

The progress of the nitration is indicated in the curve (Fig. 37, p. 226), on which I may offer the following remarks:—

1. The nitrate has developed with extraordinary rapidity. This may be seen from the following table of effluents, which gives in the first column of each heading the original results and the chlorine; in the second, the results calculated to a uniform 10 parts of chlorine, to admit of comparison:—

TABLE OF COMPARATIVE NITRATION.—PARTS PER 100,000.

	Garfield : Manufacturing		Garfield Domestic		Dibdin : Sutton.		Cameron Exeter.		Scott-Moncrieff.							
									Ashtead.						Caterham.	
									I		II.		III.			
Chlorine ...	22·4	10	11·0	10	12·8	10	7	10	7·5	10	6·4	10	5.5	10	13·3	10
N as Nitrite					·067	·052	trace	trace	trace	trace	·06	·09	·034	·062	·346	·260
N as Nitrate					1·53	1·20	1·06	1·51	9·0	12·0	5·98	9·35	4.34	7·9	9·0	6·76
Oxidized N	1·67	0·75	0·95	0·86	2·20	1·25	1·06	1·51	9·0	12·0	6·04	9·44	4·37	7·96	9·35	7·02

2. The formation of nitrite is much less marked; it rapidly reaches a maximum and then declines.

3. The free ammonia has been almost completely oxidized; at the same time it was noticed that the original yellowish colour, black suspended matter and sewage odour had disappeared.*

The following figures give the oxygen relations which I found for the first and last trays:—

PARTS PER 100,000.

	Dissolved Oxygen. cc. per litre.	Oxygen consumed by organic matter.	Available Oxygen.
Jan. 28th—			
Original	—	9·54	*minus* 9·54
Last tray	—	0·39	*plus* 20·1
Feb. 8th—			
Original	0	9·05	*minus* 9·05
Last tray	6·34	0·44	*plus* 12·99

The organic matter had been very greatly reduced for so brief a time of contact, and the effluent was in a state of rapid natural purification by means of its "available oxygen" (p. 103). When allowed to stand, the oxygen of the nitrate is utilized for the burning up of organic matter, *provided the latter has been properly fermented*, as in this case it has, and the effluent can thus be finally purified by a denitrifying bed.

In the trays described above the quantity of available oxygen is obviously far greater than would be supplied by any process of mere aeration, hence, as I have previously stated, such an effluent could be easily "finished" by a fine filter without fouling the latter, or could be beneficially applied to a small area of land, or mixed with a river of moderate volume not only without pollution, but possibly with an actual benefit to the stream.

The principle of dividing the bacteria into separate zones, where each class can naturally choose its own habitat and work successively to others is paralleled by the rotation of crops. Of the antagonism and symbiosis of bacteria we have already spoken in Chapter V.

---

*It is stated that "by transposing the trays so as to upset the natural survival of organisms in the sequence, the whole process was arrested, a high-coloured and inferior effluent being the immediate result, and one or two days were required to re-establish the conditions that had been disturbed."

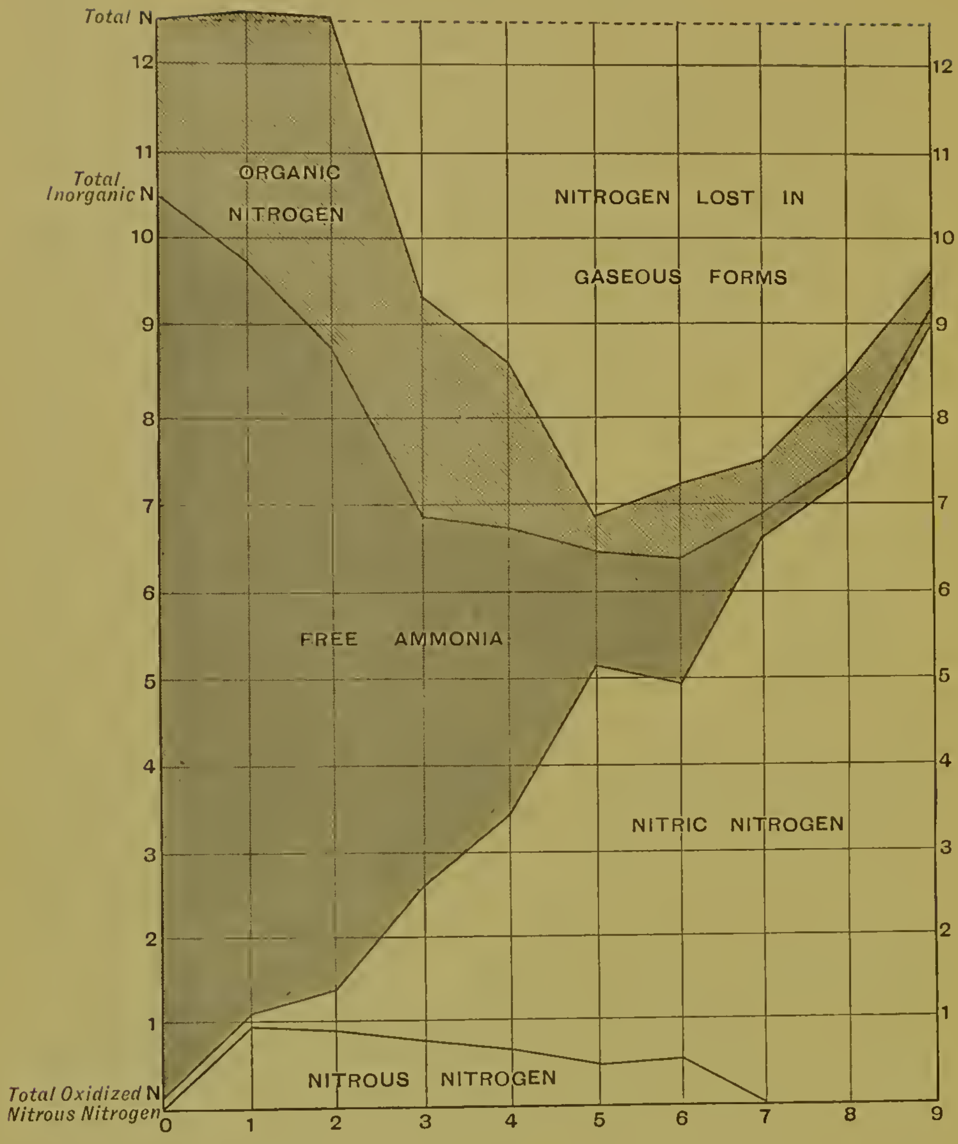

FIG. 37. CHANGES OF NITROGEN IN OXIDIZING TRAYS.

Dr. Sims Woodhead, in some experiments on coke-breeze filters erected on the upward filtration principle at the Claybury Asylum, states that in samples taken from the deeper parts of the filters, anaerobic organisms were more numerous, and ammonia was present in large quantity ; " while taking the sewage as it ran from the surface," aerobic organisms prevailed and oxygen was present, with the result that nitrates were the predominant feature. In both cases those species were specially developed, " which had a very great power of peptonizing gelatine, of setting free marsh gas from sugar or possibly from cellulose, and ammonia from nitrogenous compounds."

From other experiments he recognized "that there was a sharp line of distinction between the work done by the anaerobe, and that by the aerobe, and that the two processes should be kept as separate as possible." In this filter, natural working had established separate zones for the two operations, but being too close in one apparatus, they were liable to vary and intrude on one another, and a smell was sometimes present.

Installations on Scott-Moncrieff's principle have been working in many places in South Africa, where frost does not present any difficulty by retarding the work of the organisms. In cold countries a slight protection seems to be sufficient. At Caterham Barracks, England, the filter-house is enclosed in a brick building with a concrete roof. These works were constructed for the War Office, in 1898, to deal on the Moncrieff system with about 16,000 gallons daily of an exceptionally strong sewage. In the intensification within a small area (the whole space occupied being about 200 sq. yds., the cultivation tank 42ft. × 20ft., and the nitrifying trays about the same), probably the work which is being performed approaches to the limits of the amount and strength of sewage that can be dealt with without dilution. When it is stated that something like 2,000 lbs. of butcher's meat are consumed every day, and that to obtain a completely successful result the organic nitrogen must first of all be entirely changed by the anaerobic fermentation, either into a gaseous form, or into nitrogen as ammonia, it may readily be understood how rapid and active the process must be. As much as 35 parts of ammonia per 100,000 have been found in the hydrolysed sewage, and over 29 parts of nitric nitrogen have been obtained from the trays. I have never before experienced such large figures from nitrification.

In September, 1899, I collected and examined sixteen samples at Caterham, extending over a period of a week, (p. 24) and representing two cycles of 24 hours, when the filter was producing effluent at an average rate of 340,000 gallons per acre. The average results were :—

	Raw Sewage.	Tank Effluent.	Finished Effluent.
Chlorine	15·1	14·8	13·3
O consumed	14·97	9·25	2·71
Nitrous Nitrogen	trace.	trace.	0·346
Nitric Nitrogen	...	...	9·0
Organic Nitrogen	4·0	2·7	0·67
Ammoniacal Nitrogen ...	13·2	14·9	5·0
Total Nitrogen	17·2	17·6	15·02

The percentage purification was :—

	Oxygen consumed.	Organic Nitrogen
Raw Sewage to Tank Effluent ...	40	32·5
Ditto to finished Effluent	82	83

The Caterham plant is also instructive from an agricultural point of view, because a small sewage farm, almost sterile, on account of the chalk forming nearly the entire surface, lies with a very steep slope immediately below. Before the apparatus was put to work, the crude sewage, partly strained, was passed over this land with small manurial effect, but occasioning constant complaint on the score of nuisance. Such a soil is excellent for the purpose of absorbing an excess of liquid, but is not an active medium for dealing with crude sewage as manure. Now it appears that the farmer, looking at the thing from a rough practical point of view, is anxious to obtain the sewage at all stages of treatment, and would be glad to take a much larger quantity than is supplied, as the effluent is clear and odourless, while the vegetation where the effluent is applied is luxuriant.

Acting on my suggestion, Mr. Moncrieff has completed the Caterham installation by placing two denitrifying tanks after the nitrifying filter. These tanks receive the overflow from the hydrolytic tank, together with the nitrated effluent, and in this way the oxidizing filters can work to their best advantage, the purification of the effluent being completed by denitrification of the mixed liquids.

The Birmingham Tame and Rea District Drainage Board have recently selected a cultivation tank for a trial on the same scale as that at Caterham Barracks, and propose to take the effluents from this installation over several different kinds of filters, including the coal filter of Mr. Garfield.

THE MANCHESTER EXPERIMENTS, 1899.

For many years one of the most difficult problems has been the disposal of the sewage of Manchester. After many experiments, it was treated at Davyhulme on the old London plan of screening, adding milk of lime, then ferrous sulphate, sedimentation, and discharge of the clarified or filtered liquid into the Ship Canal. The sludge was stored in two tanks, holding 1,000 tons each, thence flowing at intervals into a sludge steamer which carried it to sea. But the pollution of the canal by the effluent led to interference from the Mersey and Irwell Joint Committee, and to the necessity of the adoption of some other system. The Manchester Corporation in June, 1898, instructed Baldwin Latham, Percy Frankland, and W. H. Perkin, to examine into the merits of various processes.

A Deputation of the Rivers Committee had previously reported in March, 1898:—

1. "That filtration by land is altogether impracticable, as no part of the land at Davyhulme, nor any land obtainable in the district, is suitable for such process, and your sub-Committee have ample proof of this by the experiments which, at great cost, have been made upon 25 acres of land at the works. . . Wherever they have visited the works of other authorities, in all cases the land filtration is ineffective, and is, in many cases, to be superseded by artificial methods of filtration. . . . The imposition of conditions by the Local Government Board, making the purchase of large areas of land compulsory, should be removed." They suggest a Royal Commission, since appointed, to investigate recent progress in sewage treatment.

2. "That no practicable system of precipitation by chemicals alone has been laid before them which will meet the requirements of the Mersey and Irwell Joint Committee." [The experiments had been very elaborate, and are detailed in the City Reports of 1897 and of previous years.]

3. They agreed that the method nearest to natural action and "most reasonably practicable and reasonable for adoption" was the biological filter or bacteria bed, such as had been seen in operation at various places.

The land available at Davyhulme for all disposal purposes is 165½ acres and the three experts soon concluded that this area was ample for the necessary works to purify the sewage including storm-water—the works existing at the time occupied 27½ acres. They pronounced adversely on the alternative proposals of treatment of a tank effluent on land, and the Culvert scheme for conveyance of the present effluent through a tunnel to the tidal part of the Mersey.

The experimental plant of 1899 consisted of three independent sections:

1. *Bacteria Beds*—These were five in number, *with sides having a slope of two to one*, filled with 3ft. of clinker of the following sizes:—

A passed 3in. mesh, rejected by 1in. mesh.
B " 1in. " " " ¼in. "
C " ¾in. " " " ¼in. "
D & E " ½in. " " " ⅛in. "

The distribution on each bed is effected by a main wooden trough with six branches, laid on the surface, and perforated with holes near the bottom. A similar arrangement of drain pipes collects the liquid below. Two of the filters are high, and two low level, E being extra: A, B, C and D have each an effective area of $\frac{1}{16}$ acre.

A and B were started with *settled* sewage in Sept. 1898, run on at first once, then twice, and finally three times a day. Raw sewage *(screened through a grid)* was commenced on Oct. 27th, 1898, and was increased after a time to four fillings per day. The times in each cycle would now be: filling ¾ hour, resting full 2 hours, emptying ¾ hour, resting empty 2½ hours. *After a week, the surface of bed A showed signs of clogging, so settled sewage was again used.* Subsequently the time of filling A was shortened to ¼ hour, and of emptying to ½ hour, to give a longer period of rest, and also because it was thought that by "rushing" sewage on to the filter *a larger amount of air would be entangled with it.* The result would belong to the partially aerobic class *but with as much as possible avoidance of suspended solids.* Samples in all cases were taken at short intervals and mixed for analyses. No other details are given of the sampling (See Chapter II).

Beds C and D were first used together in April, 1899, being filled twice a day *with settled sewage*, with ¼-hour filling and two hours contact.

II. *Septic Tank System.*—The tank was built of concrete, 40ft. × 12ft., with an arched roof 9ft. 2in. high, and air-tight manholes. The rest of the construction was as at Exeter. The beds were six, with vertical concrete walls, the total area of filtering material being 196 sq. yds., and the depth 4ft., composed as follows from the bottom upwards:—

1ft. clinker between 3in. and 1in. mesh.
2ft. 9in. " " ¾in. " ⅛in. "
3in. residue from above, passing at ⅛in. "

Raw unscreened sewage was passed through, but not so regularly as at Exeter.

III. *Roscoe Filters*—These are two in number and were first used in December, 1895. They are each 12ft. 6in. by 18ft., or 25 sq. yds., with a depth of 4ft., filled up to 3ft. with filtering material consisting of rough clinker, graded coke or cinders, and a covering of clean gravel. Three, and afterwards four fillings daily of *chemically-precipitated effluent* were made in periods like the bacteria beds.

It became evident that the main difficulties with contact beds were due to their being used chiefly as simple strainers, and that a previous preparation of the sewage was necessary. Except with the septic tank, this had taken the form of screening, sedimentation, or precipitation.

One of the most important features of the enquiry was a comparison between a closed and an open septic tank. The former, on the Exeter model, has been described at p. 213. For the latter, one of the large precipitation tanks at Davyhulme was used, raw sewage being allowed to flow over the end sill in a very thin stream, passing through the tank almost continuously from Feb. 1899, at a rate of 1,700,000 gallons per 24 hours. Similar phenomena to those at Exeter are described, the liquid becoming covered with a scum which excluded the air, while "up to the present time the only notable quantity of sludge which can be perceived . . . is immediately beneath the inlet penstocks . . . an enormous quantity of the sludge which would otherwise accumulate has been destroyed in this way." The effluents from both closed and open tanks are shown to be exactly similar.

With reference to the question of closed or open septic tanks, I may remark that some of the advantages of the former are that the gases can be utilized and all smell avoided, that the temperature is more even, and there is no interference from frost or wind. At the same time it was found at Manchester that the outfall sewage was 10° F. warmer than the temperature of the air.

The *closed* tank and *single* contact gave an effluent which "generally resisted putrefaction in the incubator test, in consequence of its containing a comparatively high proportion of nitrate." The effluent from the *open* tank was passed through the beds C and D, and by the "double contact," a better result was naturally obtained. "With four fillings per day, every sample was non-putrescible, and well within the limit of impurity." In other instances where the Mersey and Irwell Joint Committee's standard (1 grn. per gal. of O absorbed in four hours, and 0·1 grain albuminoid NH_3) was infringed, it was shown to be due to trade refuse, "which, being non-putrescible, does not cause nuisance in the Ship Canal." "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." (See Chapter III., p. 43 ; Chapter V., p. 104).

The observation is confirmed that by mixing a nitrated effluent from a "second contact" bed with that from a first, a liquid is obtained which withstands the incubator test, and it is suggested that this is a novel means by which only one-fifth of the total acreage of the filters need be at a lower level.*

A practical advantage accruing from these experiments is that the area of the second contact beds may be considerably reduced, so that in many cases it is possible to place the outfall works on a site that would otherwise not be available. At Manchester experiments have apparently not yet been made on the lines which I indicated some years ago of introducing a portion of the nitrated effluent into the septic tank itself. It is obvious that the denitrification change which takes place on mixing the effluents from the first and second contacts is due to the reaction between the nitrates in the second and the organic matter in the first, and that this change could be induced earlier in the process as soon as the organic matter is in a soluble reacting condition. It is also clear that a denitrification change can be more economically conducted in a tank which is continuously full, than in a filter bed constructed for aeration. The maximum nitrification takes place with most energy in those liquids in which the organic matters, especially carbohydrates† are a minimum, and therefore a denitrification change effected during the anaerobic preliminary stage, by reducing the oxygen-consumed figure to a greater extent than would be the case if the change were only due to hydrolysis, yields an effluent which contains its nitrogen in the most available form for the changes of which nitrification is the final result. Thus for example, a hydrolysed effluent with, say an oxygen-consumed figure of 3, and unoxidized nitrogen 10 parts, on passing through the filters often yields not more than 3 parts of nitric N ; if however, a portion of this liquid be returned to the tank, it will so reduce the O consumed figures, as to allow the nitrification to approximate to the theoretical amount.

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* Probably the previous observations of Adeney, Scott-Moncrieff (Patent 4994, March, 1898), and others, had been overlooked: compare also my lecture at the Sanitary Institute on December 9th, 1896 (*J. San. Inst.*, xviii, 1, p. 75).

† R. Warington, J.C.S., May 1900.

The Report of the experts finally recommends

> that the sewage, as it arrives at the works, be submitted to an efficient process of screening (or to roughing tanks), then passed through the present open tanks "provided with submerged walls and floating scum-boards to retain the matters in suspension," and afterwards to double-contact beds of an area of 60 acres, and a depth of 3·33ft., with four fillings per 24 hours. The dry-weather flow of sewage being 30 million gallons, the quantity dealt with by the filters is half a million gallons per acre, allowing one day per week rest. The open sedimentation tanks were to be increased so as to hold 15 million gallons; they would therefore change their fluid contents in dry weather every twelve hours. *Report Manchester Rivers Committee*, Jan. 22nd, 1900.

As to storm-water it was found that in place of being merely diluted sewage, the chlorine numbers showed that the sewage was hardly diluted at all, while there was even a greater amount of oxidizable matter in the first flush than in ordinary sewage. They advise that during a storm the flow of sewage should be dealt with in the system of tanks, and double contact-beds—" the excess of flow, after passing through roughing tanks, should be taken to specially-prepared bacteria beds of an area of at least 25 acres." After a storm the beds were proved to have shown no decrease in efficiency.

In answer, the Local Government Board decided that a larger area of land must be purchased, "over or through which the sewage after it had left the bacteria beds should pass," also (Oct. 4th, 1899) "that not less than 92 acres of filter beds shall be provided for the treatment of sewage by double contact; and that the filter beds be worked in cycles with the usual provisions as to storm-water" (Chapter VI. p. 118). I hold, however, with the general opinon that these requirements are unnecessarily onerous. In a further report of 22nd December, 1899, the experts support their previous estimate of 60 acres, stating that by "preliminary septic sedimentation" they have obtained an improved effluent, also that they work most successfully with 6 hour cycles 6 days per week, but that the exact length of the cycle must vary according to the nature of the sewage. Continuous incubation experiments showed that the effluent improved the water of the Ship Canal, that by subsequent land filtration the effluent was actually deteriorated, and that therefore the land clauses were superfluous. The City Council adopted the report with reservations as to plans.

CHAPTER XII.

Agricultural Value of Bacterial Effluents—Conservation of the Valuable Constituents of Sewage—Rainfall and Storm Water.

Distribution and Distributors — Modules — Adams' Syphon — Ridgway — Cameron's Alternating Gear—Stoddart's—Candy-Caink—Moncrieff.

Trade Effluents — Classification — Chemical and Mechanical Treatment—Recovery of Products—Wool Grease—Local Regulations—Relation to the Bacterial Process.

STRONGLY nitrified bacterial effluents have proved of high agricultural value, suggesting that in this way the nitrogen of sewage would be prevented from being lost to the community. At Sutton about four and a half acres of peppermint are at present cultivated by irrigation with a bacterial effluent. At the time of my visit on the Newmarket enquiry, I noticed that the plants were vigorous and the ground looked healthy. From the report of the surveyor, it appears that the yield of peppermint oil from the 2¾ acres cultivated in 1898 was 61½ lbs., sold as first-class oil at 24s.3d. per lb.

Prof. Maerker of Halle,* assigns the following relative values of different nitrogen compounds for plant food, as derived from cultivation methods :—

Nitrogen as nitrate ...	100
„ „ ammonia ...	85 to 90
„ „ albumen ...	60

and remarks that "the nitrate destroyers are usually present in stable manure, and cause a deplorable loss to agriculture, amounting in Germany to a sum of several million pounds annually."

Consequently the highest natural nitrification of sewage in the third stage is necessary both for healthy disposal and to prevent a continual waste of valuable nitrogen (p. 101). This leads to a consideration of the attempts that have been made for the

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* *Kew Bulletin*, 1899, No. 144.

CONSERVATION OF THE VALUABLE CONSTITUENTS OF SEWAGE.

It has long been recognised that since the fertility of the soil is reduced by continual cropping, it must be renewed in the land by manure if the cycle of existence is to be maintained—the excreted matters being again worked up by plants into human and animal food. But the dismissal of a portion to the sea as sewage disturbs the rotation, and, by impoverishing the land, will eventually starve both the plant and the animal. An aspect of this fact aroused wide attention from the address of Sir William Crookes at the British Association at Bristol in 1898, in which the danger of exhaustion of the nitrogenous food supplies of the world was emphasized.

In his book on the "Wheat Problem," p. 38,* he estimates that in the sewage and drainage of towns we "hurry down to the sea fixed nitrogen to the value of £16,000,000 per annum."

The problem had, however, been clearly seen by Liebig and others years before. When chemical precipitation was in vogue, it was hoped that the sludge would be useful as manure, and thus restore the material to the land; but the product so obtained was not of sufficient agricultural value.

Sir Edwin Chadwick and his school strongly advocated the principle of sewage farms, with direct application to the land, but for reasons that I have described in Chapter VI., the system was not satisfactory.

The chief causes of failure in the two cases were (1) the very large volume of sewage that had to be continuously dealt with, (2) its property of fouling or clogging, (3) the relatively small amount of important manurial ingredients like phosphates, potash, and nitrogen it contained in proportion to the quantity of water, (4) the unsuitable form in which the organic matter existed, rendering it almost poisonous to vegetation. The last difficulty suggested that if the liquid was properly prepared or matured by a fermentation process analogous to that by which a farmer "ripens" manure, its nitrogen and other constituents might be more readily utilized by plants. Mr. Davies† held out great hopes in this direction, while Mr. Daniel Pidgeon,‡ dealing with the bacterial purification of sewage, shows forcibly the practical value of highly nitrified effluents for all kinds of cultivation.

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* John Murray, London, 1899.

† *Journ. R. Agric. Soc.*, Oct. 1899.

‡ Ibid.

Mr. Scott-Moncrieff* has pointed out that by proper treatment a 90% nitrification of the total nitrogen in ordinary sewage could easily be attained, and that this, " based on the cost of nitrate of soda, works out to about £14,000,000 per annum on the whole sewage of the United Kingdom," a saving which nearly recovers the waste mentioned by Sir W. Crookes. These highly-nitrated effluents also contain plant-food in nearly ideal proportions, according to the standard solution adopted by Nobbe, which contained in parts per 100,000 :—

Lime	16	Phosphoric Acid	7
Magnesia	3	Chlorine	21
Potash	31	Oxide of Iron	·5
Nitrogen	8·2		

Dr. Voelcker, in a letter to Mr. Pidgeon, speaks of this solution as " containing those constituents and the amounts of each which have been found to be requisite for plant growth, and the absence of any of which or the supply in markedly lesser quantity of which would produce deterioration while the larger supply of any of which would not be attended by increased benefit."

By experiments on plants I have found these effluents to give great fertility.

As regards the mineral constituents of different sewage effluents not much information is recorded. I have lately examined in this sense an average sample prepared from a large number of specimens of the final flow from the Sutton beds. The ordinary analysis gave in parts per 100,000 :—Total solids 94·96 ; suspended matter, none ; chlorine, 9·57 ; nitrogen as nitrate, 3·18 ; as nitrite, 0·157 ; as ammonia, 0·33 ; organic nitrogen, 0·372 ; total nitrogen of all kinds, 4·039.

Further examination of the total solids showed :—

	PARTS PER 100,000.
Fixed mineral matter	74·0
Volatile and organic matter	20·96
Actual sodium chloride	15·77
Soda, in other forms (sulphate, carbonate, etc.) calculated as Na_2O	1·32
Total soda as Na_2O	9·67
Total potash as K_2O	3·30
Phosphate as P_2O_5	0·30

That the nitrogen had been almost entirely " mineralized " was shown by the low percentage, 1·77%, of organic nitrogen retained in it, proving that the residues were mainly carbonaceous. 100 parts of total solids would correspond to—

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* Southampton Sanitary Congress, 1899 : *J. San. Inst.*, vol. xx., part 4.

Total N 4·25 : K_2O 3·48 : P_2O_5 0·32
Mineral matters 77·93 : Organic 22·07

Probably much phosphate has been retained in the filters. The ferruginous matter in coke, derived from the pyrites of coal, is clearly seen as a red-brown ochry coating in parts when a filter is dismantled: this would absorb much of the phosphorus as phosphate of iron. Polarite and other highly ferruginous mixtures would have a still greater effect. Disused filtering materials must consequently contain a large proportion of phosphate.

The difficulty of utilizing any of the valuable constituents of sewage resulting from their extreme dilution, prevents evaporation, distillation, or any of the ordinary chemical methods from being economical. The free ammonia present would be a marketable article if it could be cheaply extracted. In 1882—1883, Dupré suggested its separation by blowing air through the liquid and absorbing the ammonia in acid, the aeration at the same time improving the sewage and reducing the nuisance at discharge. He states with reference to London, that the sewage contains 3 to 4 grains of ammonia per gallon, equal to 31 tons of ammonia in 140 million gallons—one day's discharge, giving 120 tons of sulphate of ammonia, worth from £14 to £20 per ton, or a total value per annum of about £400,000. "By blowing air into the sewage much of the ammonia would be expelled, and if only a fraction of it were recovered, the expense of aeration would be covered."

It does not seem that this idea has been attempted on a large scale. It would include, in common with other artificial methods that we have seen, a continuous mechanical expense, hence natural nitrification is more economical. Utilization of both the saline and organic nitrogen by means of sulphuric acid is one of the features of the Liernur process (p. 153).

RAINFALL AND STORM-WATER.

In all systems of sewage disposal, provision for storm water and rain must be provided. A rainfall of 0·1 to 0·2 inch in an hour increases the outflow of a sewer to five or more times its volume, but there is no exact relation between the rainfall as ordinarily recorded and the increment of flow at the outlet, the size, length, and inclination of the sewer greatly influencing the result. At Exeter five-eighths of the ordinary rainfall is estimated to find its way into the sewers.

Mr. Silcock,* from gaugings at King's Lynn, finds that "the ordinary dry-weather flow of sewage per acre of a purely urban district, with an average population of seventy-five persons per acre, consuming 20 gallons of water per head per day, is 20 cubic feet (125 gallons) per hour. A rainfall of ¼ inch in 24 hours, or approximately $\frac{1}{100}$ inch per hour, will amount to the same discharge as the dry-weather flow per acre, assuming that the streets are paved, and that only 50 per cent. of the actual rainfall finds its way into the sewers. In other words, a rainfall of $\frac{1}{100}$ inch per hour will double the ordinary dry-weather flow. Now a rainfall at the rate of ¼ inch *per hour* is a common occurrence, which would mean multiplying the ordinary sewage flow by 25, and short storms at the rate of ½ inch per hour are not infrequent when the ordinary sewage flow is augmented 50 times. . . . For a town with a population of 100,000, if the whole of the sewage and rainfall had to be taken to the purification works, the ordinary maximum sewage flow at 20 gallons per head would be at the rate of 4,000,000 gallons per 24 hours, and if the sewage were treated on bacterial intermittent filters, 4 acres of filters would be required, but to deal with a rainfall of ¼ inch per hour would require 100 acres of filters, and if the sewage had to be pumped it would require 25 engines and pumps each capable of dealing with a dry-weather flow to cope with the combined rainfall and sewage.

It is therefore evident that the whole of the rainfall cannot be taken to the purification works and that after a certain degree of dilution has been reached, the storm-water must be discharged into the streams."

Both the quality of sewage and its quantity as affected by local circumstances therefore determine the choice of a system of sewerage. Under the "combined system" the effect of rain must not be considered as simple dilution, since the rain-water carries the washings of the surfaces over which it has travelled. Where the rock, or a clay bed, is near the surface, the showers will run off almost unchanged. From manured or peaty land there will be an addition of brown humous liquids which are particularly difficult to decolorize. We have already described (p. 6) the polluted character of washings from streets.†

For the safety of the sewers and the avoidance of flooding of basements, it is necessary under the combined system to construct special arrangements for storm overflow. Without storm overflows in a sewage farm scheme the ground is liable to become waterlogged, and in a filtration process the excess of water by its volume and velocity tends to derange the purification plant, hence it is usually allowed to escape from the sewers by special outlets when above a certain amount, carrying with it a mixture of the unpurified sewage.

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* Leeds Sanitary Congress, 1897.

† See also the Manchester observations on storm-water, p. 233.

The combined system also involves the construction and maintenance of sewers very much larger than the volume of the regular flow, in order to provide for occasional contingencies. This greater capacity presents inducements to the disposal of grosser refuse which would not be tolerated in a smaller sewer, and often it is impossible—except at rare intervals—to properly flush the entire surface of these large channels.

The "separate system," in which the sewage proper is kept apart from rainfall and storm-water, has conduits of such size only as to preclude the possibility of the sewage becoming stagnant therein, the size being governed by the bore of the water main, since if a given diameter of pipe supplies all the water needed, a little above the same diameter should be sufficient for an exit.

Mr. Silcock proposes that the rainfall sewers of a separate system should be provided with leaping weirs discharging into the sewage sewers to separate the foul street washings from the later discharges of heavy rainfalls.

Storm-water passing rapidly off the land carries with it disease germs, as is shown by the repeated occurrence of epidemics when a sudden storm succeeds a period of drought. But the liquid is ordinarily supplied with abundance of the liquefying and oxidizing bacteria, which if it be allowed to subside in auxiliary reservoirs will effect its purification rapidly, aided by the oxygen derived from the air, and by the nitrites and nitrates that rain-water always contains. The sand, chalk, or especially the clay, may be a long time in subsiding, but when deposited will leave the water comparatively pure, and fit for flushing sewers, watering roads, or for supplying the deficiency in rivers during dry seasons.

Whatever system be adopted the raw storm-water of populous districts should never be allowed to pass in large volumes at the beginning of a storm directly into a stream. The general consensus of opinion is that if the first foul storm-water be treated as ordinary sewage, the subsequent rain-flow becomes so dilute that it can be discharged, with only a slight treatment, into a river. The Manchester experts placed a limit of time of two hours after the commencement of the storm. Many towns adopt a volume limit. Thus, Mr. A. M. Fowler, at Stockport, made provision for an escape after eight times the dry-weather flow; other places in Lancashire and Yorkshire allow 6 or even 5 to 1. By the Leicester Extension Act, 1891, the overflow culvert came into action when the rainfall increased the dry-weather flow of 35 gallons per head to 60 gallons, but in this case the overflow passes into the river Soar, which has a flow during dry weather of only about 6 or 7 million gallons per day, so that the storm-water is actually useful for flushing the river bed.

I have found from analyses—

1. That, after the first flush, the chlorine content varies with the rainfall.

2. That with low chlorine and high rainfall, higher nitrification is obtained.

3. That, as might be expected, the later diluted sewage comes within the usual standards of permissible impurity, therefore could not, under them, be excluded from streams.

With reference to bacteria beds, in the words of Mr. Dibdin "it was not a question of whether they had more or less water, it was the amount of organic matter that was put on the bed, and if that was not materially increased it mattered not how much storm-water was put upon it. They had been able (at Sutton) to put three or four times the quantity of storm-water on to a bed than the volume of sewage they had put previously." As a matter of fact, an occasional flush of storm-water through a bacterial system is advantageous, as it removes some of the products, and so stimulates the bacteria to fresh activity.

The regulations of the Local Government Board have been briefly alluded to. Their observations on storm-water are:—

> "As at present advised, the Board consider that whatever system is adopted as a means for dealing with the sewage, it is necessary that provision should be made in the scheme for (1) Treating fully as ordinary sewage a volume of mixed sewage and storm-water equal to three times the daily dry-weather flow of sewage, and (2) Dealing with the excess of storm-water up to six times the dry-weather flow, or a balance of three times the dry-weather flow, either by passing it through a special and separate storm-filter of sufficient extent, or by delivering it on a special area of prepared land other than that in use for the treatment of the effluent from the ordinary tanks and filters." . . . . "If a special storm-filter is provided for this purpose, it should be of sufficient extent to allow a rate of filtration of 500 gallons per square yard per diem."

Mr. A. J. Martin,* remarks on the wide difference between the dry-weather sewages of different towns, so that if a hard and fast relation of volumes be prescribed as above, "the diluted sewage which one public body may discharge without treatment will be considerably stronger than that which another authority will be called upon to purify."

The Local Government Board insists that fixed weirs shall be used, which will only come into operation when the sewage has been diluted with five times its volume of storm-water, that is, when a certain rate of flow in the sewer is reached. But Martin proves that the amount of dilution secured by a fixed weir is variable, and will at times be considerably less than the works are intended to secure.

Among the advantages of the bacterial processes involving a large anaerobic preliminary chamber, is the ease with which the works can be adapted for dealing with storm-water. In such systems provision is made for the subsidence of solids, as well as for their liquefaction, as a tank constructed to hold the dry-weather flow of a sewage for 24 hours would admit of six times the dry-weather flow passing through such tank by reducing the time of stay from 24 hours to 4 hours. The rate of flow under such conditions would still be so slow as to ensure the retention in the tank of the whole of the suspended solids, and these would therefore accumulate during stormy weather to be digested by the tank at leisure during the dry-weather periods. A curious anomaly arises out of these considerations. If the time of sojourn in the tank is reduced owing to the rate of flow through the tank being increased, the liquid products of hydrolysis usually contributed to the effluent from the stay in the tank will not exist in the effluent water to the same extent. In other words, the effluent from such a tank during a storm will be purer than from the tank in dry weather proportionately to the rate of flow, even after due allowance has been made for dilution, provided only the rate be not so high as to bring untreated suspended matter to the outlet. Mr. Martin has well illustrated this point in the above paper, in which he has shown that the Barrhead Works, already described will fulfil these conditions. As a matter of fact, the velocity of flow in the tanks at Barrhead with three times the volume of the dry-weather flow passing through them, would only amount to 1⅞in. per minute. With six times the dry-weather flow, therefore, the velocity would not exceed 3¾in. per minute, which is obviously so slow a rate as to be powerless to disturb solid matter in the tank.

* *J. San. Inst.*, xx., 4, p. 624.

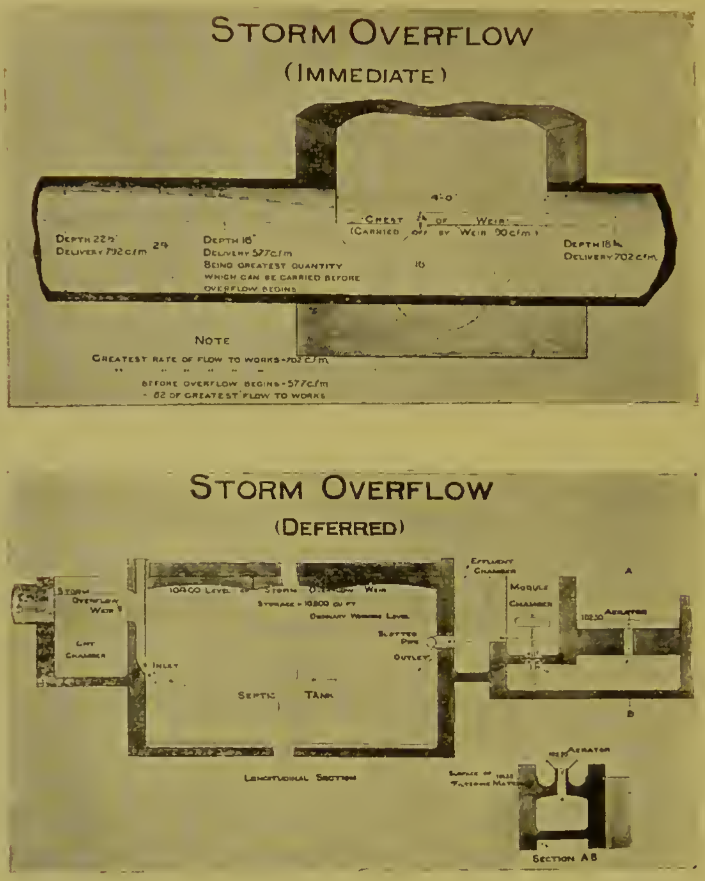
STORM OVERFLOW
(IMMEDIATE)
4·0
CREST OF WEIR
(CARRIED OFF BY WEIR 90 c/m)
DEPTH 22½
DELIVERY 792 c/m
24
DEPTH 16
DELIVERY 577 c/m
BEING GREATEST QUANTITY
WHICH CAN BE CARRIED BEFORE
OVERFLOW BEGINS
16
DEPTH 16½
DELIVERY 702 c/m
NOTE
GREATEST RATE OF FLOW TO WORKS = 702 c/m
BEFORE OVERFLOW BEGINS = 577 c/m
= 82 OF GREATEST FLOW TO WORKS
STORM OVERFLOW
(DEFERRED)
STORM OVERFLOW WEIR
LIFT CHAMBER
104.00 LEVEL OF STORM OVERFLOW WEIR
STORAGE = 10,800 CU FT
ORDINARY WORKING LEVEL
SLOTTED PIPE
OUTLET
INLET
SEPTIC TANK
LONGITUDINAL SECTION
EFFLUENT CHAMBER
MODULE CHAMBER
A
102.50
AERATOR
B
AERATOR
SURFACE OF FILTERING MATERIAL
SECTION AB

FIG. 38. STORM OVERFLOWS AT BARRHEAD.

In Fig. 38 Mr. Martin's arrangement of weir and regulated flow by means of modules, to provide for the variation of flow during periods of storm, is shown.

DISTRIBUTION.

The methods of distribution obviously depend on the character of the site for the disposal works. In many places the low-level sewage has to be raised to the works by pumps, lifts, or ejectors, and the problem becomes an engineering one.

It has been remarked that a really anaerobic treatment in the first stage, like Cameron's or Moncrieff's, requires no fall, the sewage simply flowing in below and flowing out above. In terraced beds fed from the top, like those at Sutton, Hampton, and elsewhere, the fall to be provided includes the sum of the depths of the beds and of the distributing apparatus. Therefore, increasing the depth of material, although it may economize surface area, will generally add the expense of raising.

Ordinarily, the sewage, owing to its fluctuations, has to be controlled by penstocks and valves at the entrance and exit. A restraint at the entrance involves storage. " Holding up " is temporarily closing the outlet valve so that the filter fills with fluid. In the Lowcock filter and others, the entrance is controlled and the outlet always open.

The variation in the flow of sewage occasions great difficulty where the admission is direct to bacteria beds, but in septic tanks of sufficient capacity, the irregularity is not felt. In any case, the flow of sewage can be regulated by means of " modules."

The first module, according to Jackson, was introduced in Piedmont, for the purpose of giving a uniform discharge of water out of a main channel or canal. The height of water in the canal or river might vary, but the flow from the module remained nearly constant. It was a chamber commanded by a sluice; in the bottom of the chamber was a square orifice, in size according to the delivery required. The sluice was opened till the flowing water remained at a fixed level in the chamber. The area of sluice opening would bear a certain relation to the orifice area. Such a module, though giving for the purpose a sufficiently uniform flow, would not adjust itself except within narrow limits. A great number of self-acting modules were used on the Indian canals, especially one devised by Lunt Jarrols. In the Piedmont form a free fall is a necessity, but with self-adjusting modules this is not required, those at Barrhead (p. 242), working with a difference of level of about an inch. The arrangement consists of a module chamber having a circular opening in the bottom; through this opening is a body, conoidal in shape, attached to a float. As the head of liquid falls, so do the float and cone, making the opening larger, and *vice versâ.*

DISTRIBUTORS.

A. In the *intermittent or " holding up " system* the sewage has to be applied at intervals to a number of beds. The chief automatic apparatus for this purpose are the following :—

I. The Adams Syphon, (Adams' Patent Sewage Lift Co., York) is in operation at Sutton and other places, to control the supply of liquid to bacteria beds of the intermittent type, but is also adapted to the continuous systems. In the former (Figs. 39, 40) A is the inlet, B a scum or resolving tank, C a syphon feeding the first bed, coupled by air pipes with the domes E and F. The sluice supplying the second bed is closed while the first is filling from the feed C through the distributor G.

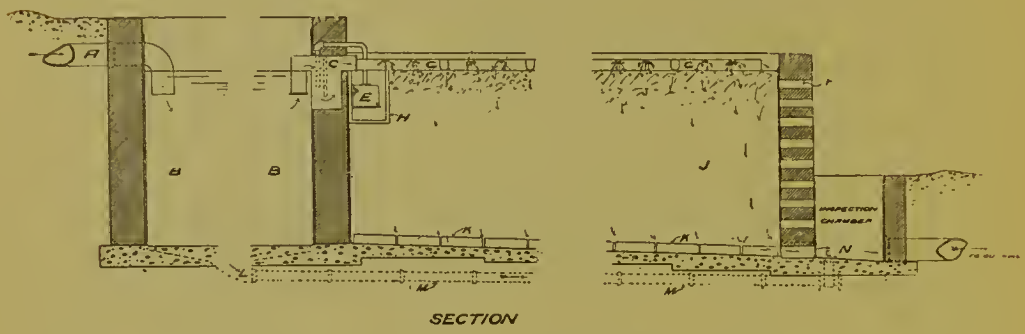

FIG. 39. SECTION OF INTERMITTENT SUPPLY (ADAMS' SYPHON).

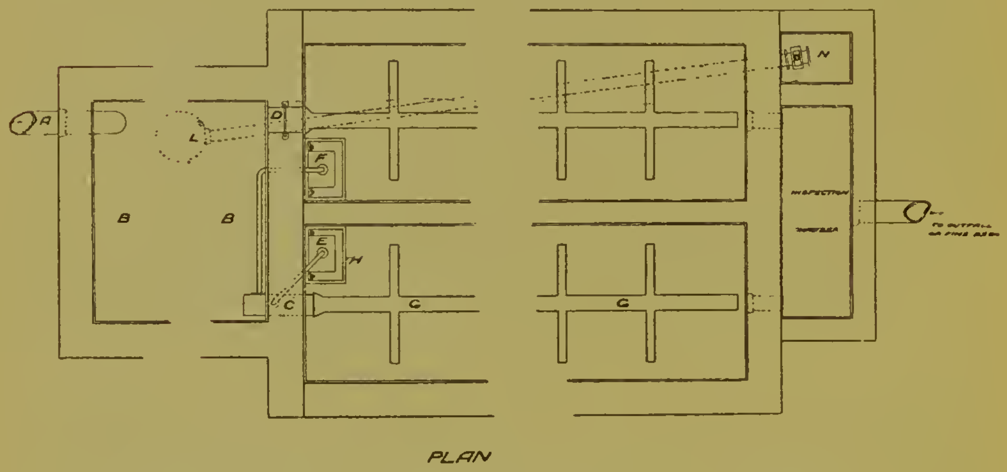

FIG. 40. PLAN OF INTERMITTENT SUPPLY (ADAMS' SYPHON).

"The feed apparatus is a plain trap-like casting through which liquid passes freely from the source of supply to the bed to be filled, until the air contained in its attached dome E is transferred by the pressure of liquid around it, as the bed fills, through a trapped air-pipe to the interior of the feed, creating an air-lock, and blocking the further passage of liquid so that the liquid rises to a higher level in the source of supply until the inlet sluice to the next bed is reached. Where an automatic discharge is also used (Figs. 41, 42), the liquid contents of the first bed will in the meantime have been discharged through syphon M, and the overdraw pipe K attached. A tap L delivers liquid to the syphon chamber, and the time occupied in the filling of this chamber will be that for which the sewage is held upon the bed in contact with the filtering material. The feed and discharge apparatus being quite distinct the one from the other, enable users to fix any desired time of contact—according to the requirements of the sewage—the balance going to aeration, a very important point which is unattainable where the supply and discharge are brought about by one operation. The second filter bed thus fills and its liquid in turn displaces air from dome R (Fig. 42), thus air is transferred to the feed C, its added bulk forcing the water seal, freeing the confined air, and again bringing on the supply to the first bed. At N is a pipe dotted, through which any accumulation in tank B may be drawn off by valve O.

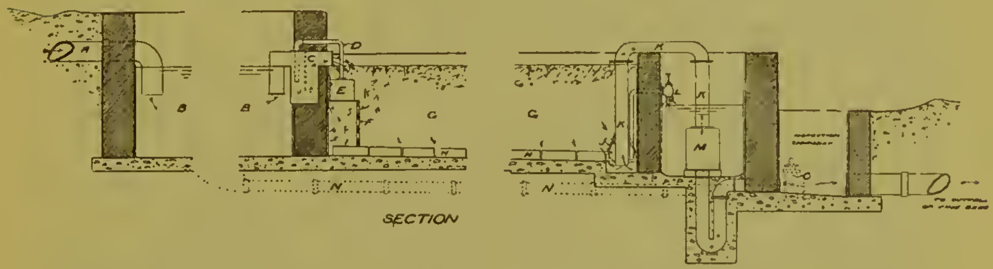

FIG. 41. SECTION OF AUTOMATIC DISCHARGE BY ADAMS' SYPHON.

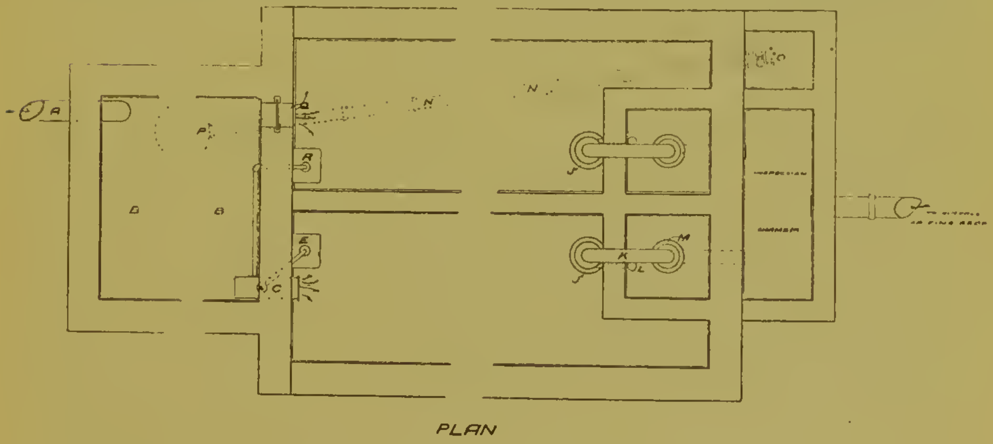

FIG. 42. PLAN.

In applying the apparatus shown in Fig. 39 to continuous filters, the feed C discharging to filter No. 1 gradually fills a receptacle into which dome E dips. This receptacle has an outlet. The taps supplying the inlet and outlet may be set so that the receptacle fills in any given time, when as in Fig. 39, the air will be transferred to the feed C, causing an air lock which will divert the sewage to the next feed or bed. With this apparatus any desired area may be flooded for a given time, sewage being sent to one area or bed after the other, regardless of the numbers used or volumes dealt with, automatically and without movement."

II. The Ridgway Automatic Distributor, made by Mather and Platt, of Manchester, is described as follows :—

The crude sewage, having been roughly screened, is received at A (Fig. 43) into a "syphon chamber," which is built to hold a given number of gallons according to the volume of sewage to be dealt with. When full, which occurs in a calculated fixed length of time, the syphon B discharges this amount, in a much shorter period (also carefully calculated and allowed for in designing the syphon), into the "Distributing Chamber" at D. In so doing, the hollow cylindrical float, C (which has been previously raised by the filling of the syphon chamber) descends to the bottom, and by a pawl and ratchet wheel causes the shaft E to revolve exactly a given fraction (according to the number of separate places to be "fed") of a complete revolution. By an arrangement of cams on this shaft, and levers on the "valves" F, one of these valves, which had been held open since the last discharge, is released, and falls by its own weight, thus closing that particular aperture to the sewage in the distributing chamber; whilst simultaneously the next valve in sequence is raised, so that the sewage flows through a fresh outlet. The action continues automatically night and day without cessation.

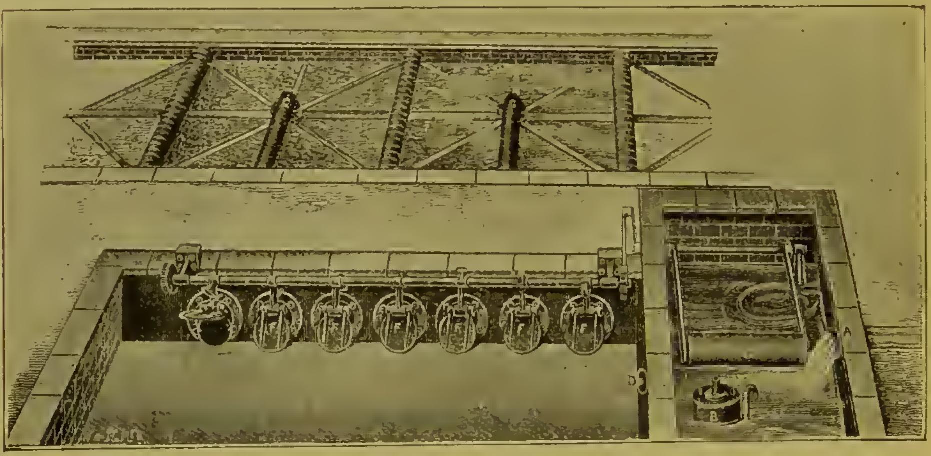

FIG. 43. RIDGWAY'S AUTOMATIC DISTRIBUTOR FOR CONTACT BEDS.

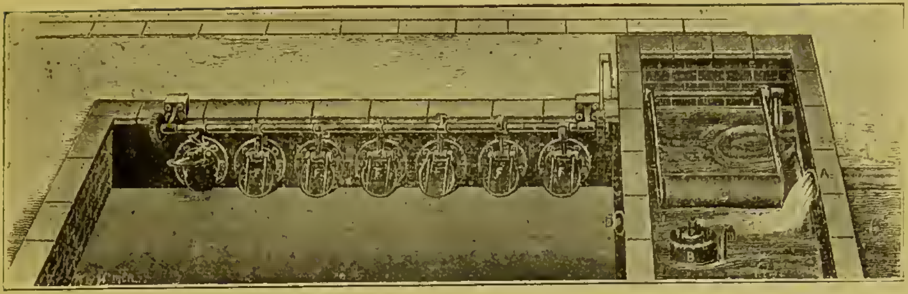

FIG. 44. RIDGWAY'S AUTOMATIC DISTRIBUTOR FOR BROAD IRRIGATION.

The sewage from the main outfall is thus broken up into measured quantities, and delivered at different outlets. About two feet of fall is taken up in doing this.

A report from Dr. Garstang in October, 1899, on the working of this distributor in connection with single "contact beds" with subsequent land filtration, at the Bank Hall Lane Works, Hale, near Manchester, states that the machine has passed 72,000 gallons per day on to 180 square yards of beds, or at the rate of 2 million gallons per acre per diem, during a period of 10 months. He gives the following average analyses :—

	Parts per 100,000.			Per cent. purificat'n by O consumed
	O consumed	Free NH_3	Albd. NH_3	
Crude sewage (screened)	5·0	2·184	0·668	—
Effluent from bed ...	1·0	0·841	0·215	80
Final land effluent ...	0·43	0·668	0·126	92

It would also appear from Dr. Garstang's report that the effluent remains at the bottom of the bed for two hours before being expelled by the next succeeding charge. This involves an increase in the capacity of the bed, and renders denitrification changes possible.

III. Cameron's Automatic Alternating Gear has been already mentioned in connection with Exeter. As used at the larger Barrhead installation, it is officially described as follows :—

> "Six of the eight filters will ordinarily be in use at once; of those in use, one will be filled at a time. As soon as a filter is full, the flow of tank effluent will be automatically diverted to the next filter,

and after a certain time, the contents of the full filter will be discharged.

Each filter will receive its supply of tank effluent through its admission valve, from which the effluent will pass into the stoneware main distributor, feeding six branch distributors.

The filtered effluent will be collected by lines of agricultural drain pipe, connected with a stoneware main collector, the latter running into the discharge valve box. Upon this box is built a discharge well of 9in. stoneware pipes.

Both the admission and discharge valves are suspended by valve rods from a lever, which is pivoted on a bearing between the admission valve chamber and the discharge well. At one end of this lever is a counterweight, so adjusted as to hold the admission valve open and the discharge valve down on its seat.

The admission valve is closed, and the discharge valve opened, by means of an actuating bucket, suspended from the end of the lever in the actuating bucket chamber. In order that both valves may not open at the same time, the upper ends of the valve rods are looped, and the lengths so adjusted that the admission valve shall come on to its seat before the discharge valve begins to open, and *vice versa*.

The opening and closing of the valves are effected by means of an overflow from a filter which has been filled. When a filter is full, a portion of the filtered effluent passes by the main collector into the discharge well. When the water in the discharge well has risen to near the level of the surface of the filter, a small quantity of filtered effluent will overflow from the well into an overflow box, and thence through a 1¼in. overflow pipe into the actuating bucket chamber of the next filter, in which the actuating bucket will then be in its lower position and full of filtered effluent. The water rising in the chamber around the bucket will neutralize the weight of the water in the bucket, allowing the counterweight to draw down the far end of the lever, closing the discharge valve and opening the admission valve. When the bucket begins to rise, a tooth on the end of the lever will bear against a cam, pivoted at the top of the rod, which lifts the valve in the bottom of the bucket, permitting its contents to escape. As the bucket nears its higher position, the tooth will slide past the cam, and the valve will fall again on to its seat.

Meantime another portion of the filtered effluent will be overflowing from the full filter into its own actuating bucket, the rate of flow being regulated by an orifice, so that the filling of the bucket shall occupy a certain desired time. The first two inches of water entering the bucket will overcome the counterweight, and rock the lever into a horizontal position closing the distributing valve. The lever will then come into a bearing on the rod of the discharge valve, the weight of which, and of the column of water thereon, will arrest its motion until the bucket is nearly full, when the movement will be completed, and the discharge valve opened, releasing the contents of the filter.

The discharge valve does not open to the full extent at once ; but, when it begins to open, the bottom of the actuating bucket strikes the surface of the water lying in the actuating bucket chamber, which rises round the bucket and retards its downward progress. The water so raised in the actuating bucket chamber escapes gradually through a small orifice in the side of the latter, the escape of the water, and hence the rate of opening the valve, being governed by the size of the orifice.

The delivery of filtered effluent to the actuating bucket chamber for the purpose of raising the bucket is stopped by means of a valve as soon as sufficient water has passed; and when the bucket has come near its higher position, the surplus contents of the chamber (above the level of the orifice in its side) are discharged through another valve. Both these valves are suspended from a small lever, which is operated by the main lever through a connecting rod. The small lever will be moving only while the main lever makes the upper half of its stroke.

The 1¼in. overflow pipes to the actuating bucket chambers are connected into a continuous ring, having branches from the overflow boxes and to the actuating bucket chambers. These branches join the main ring at a five-way cock, by turning which the filter to which they belong may be thrown out or in. When a filter is cut out, the overflow from the previous filter, which would otherwise pass into its actuating bucket chamber, is stopped by the five-way cock and diverted further along the ring to the actuating bucket chamber of the next filter.

That portion of the overflow from a filter which flows into its own actuating bucket is drawn off from the five-way cock through a disc perforated with small holes, in order that nothing may pass through which would choke the regulating orifice.

The gearing used in later installations, while in many respects similar to that at Barrhead, embodies several important improvements thereon, the chief of these being as follows:—

1. The discharge well and admission valve chamber are made in cast iron and mounted on a bed plate of the same material so as to be entirely independent of the walls.
2. The mechanical details of the gear have been greatly simplified.
3. Before each filter is filled, the tank effluent is held back for a period of from one to two hours, the quantity so accumulated filling the filters in a much shorter time than if it had been allowed to flow continuously.

This obviates Mr. Mansergh's criticism of the automatic gear, that the decreased flow in the night fills one filter so slowly that the corresponding one in the resting-full stage remains charged so long as to seriously interfere with its aerobic action.

The effluent from a septic tank, as we have shown in Chapter XI., is much more constant in volume and character than a raw sewage. The shortening of the cycle, and consequent increase in the rate at which the filters work, is not due to the alternating gear, but to the variation in the flow. Whether such gear is used or not, the filters will have to work faster when they have a large flow to deal with. The Exeter system has a marked advantage in the tank affording a means of storing the excess at the time of maximum flow, so as to discharge uniformly through the filters during the whole 24 hours. In the new works at Exeter this is specially provided for.

The objection "that the discharge valve when opened to its full diameter at the commencement causes the filtrate to be liberated with a rush, carrying with it the fine matter and fouling the filtrate," is obviated by modifying the gear so as to open the valve slightly at the commencement, gradually increasing the opening as the discharge goes on.

Mr. Graham, of Newcastle, has invented an apparatus similar to Mr. Cameron's, but claiming to be cheaper. It is described as:

> "A swinging or oscillating hopper suspended or supported on a shaft or pivots immediately above the wall dividing the filters; a float is suspended at each side of the hopper and cased in by concrete walls formed in the filters, in which the float rises and falls. There is an opening between these chambers and the filters. The action of the apparatus is as follows: The sewage is discharged into the hopper, which conveys it into one of the filters. As the filter fills, the float gradually rises until the filter is full, when the hopper is tipped over and the flow of the sewage is diverted into the other filter. Each filter is allowed to remain full for a certain time, and emptied by a syphon, the filter then receiving a rest for aeration. The apparatus is of the simplest description, and it is impossible for it to get out of order. Only one hopper is required for each pair of filters."

B. In the *Continuous System*, it is of extreme importance that the liquids should be distributed uniformly over the material.

The problem of spreading a liquid issuing from a narrow channel evenly over a broad area is not a simple one. In upward filtration it is easy, the liquid rising from the bottom naturally distributes itself throughout the filter. But when the introduction occurs from the top, there are considerable mechanical difficulties. Where sand filtration is used, as in the States, in Lowcock's and some other filters for sewage, and in the ordinary plants of the water companies, it is only necessary to protect the sand from disturbance by a coarser heavy layer of flints or stones, to run the liquid on the top, and trust to the evenness of the fine layer for equal distribution. The deficiency of aeration, and blocking of the beds, are faults of this method when applied to sewage.

With aerating filters of open material, flushing the liquids, however rapidly, from penstocks at the sides, or in the middle, leads to the formation of channels, and only a local use of the mass of material, therefore many arrangements for spreading the fluid more equally have been devised. Networks of split pipes or iron or wooden troughs are not satisfactory. Perforated pipes occasion trouble, through blocking by solid matters, therefore the ends have to be made with openings, so that the tubes can be brushed through at intervals : the corrosion of the iron by the chlorides and nitrates in the liquid also blocks up the holes. In some cases the tubes have been made of gun-metal, but this also is liable to corrosion, particularly along the lines where it may have been joined or soldered.

Mr. Stoddart of Bristol, has introduced a distributor depending on the dropping of the sewage from vertical points and not from holes : " the supply channel is a gutter in direct connection with the tank outlet, and the patent distributor consists of a number of narrow gutters arranged at right angles to the supply channel. Each section of the distributor abuts against a casting embedded in the margin of the supply channel so arranged that the tank effluent on flowing over the margins of the channels passes into the gutters of the distributor. Along the lowest part of the under surface of each gutter is placed a series of vertical points. The sewage or tank effluent entering the gutters by way of the supply channels, flows over their margins, and on reaching the under surface falls from each of the vertical points in a series of fine drops. There are no fine perforations to become clogged and the action of the distributor does not in the least depend upon the sub-division of the sewage by fine apertures or tubes, but there is a perfectly free passage." It works with only three inches of head, and is unaffected by accidents such as a discharge of sludge or continued frost. At the same time, any suspended matter present in the effluent settles in the troughs of the distributor, and must be removed by a brush from time to time. The small amount of suspended matter present in a good chemically treated effluent, or that from a septic tank of small capacity in relation to the flow, may give an appreciable amount of deposit in these troughs.

Another of the devices for even distribution is the Candy-Caink "self-propelled revolving sprinkler and aerator" (Fig. 45) of the International Purification Syndicate. This Company have installations at Reigate, Southampton, and Southwold, where the sewage after passing a catch-pit or after a first anaerobic treatment, is distributed by the sprinkler over aerobic beds. I have not yet had an opportunity of examining the process in any detail. An "anaerobic sludge-digesting bed" of large stones or clinkers, or the crude sewage after the catch-pit, discharges *continuously* by means of the sprinklers on aerating beds. The continuous action is on the right principle, as I have often emphasized the disadvantage of intermittent working in alternating and confusing the bacterial actions. Large pieces of paper, fat, fæces, and such large matters are retained in the catch-pit, and after they have been broken down therein, get carried on to and are finally dealt with in the beds.

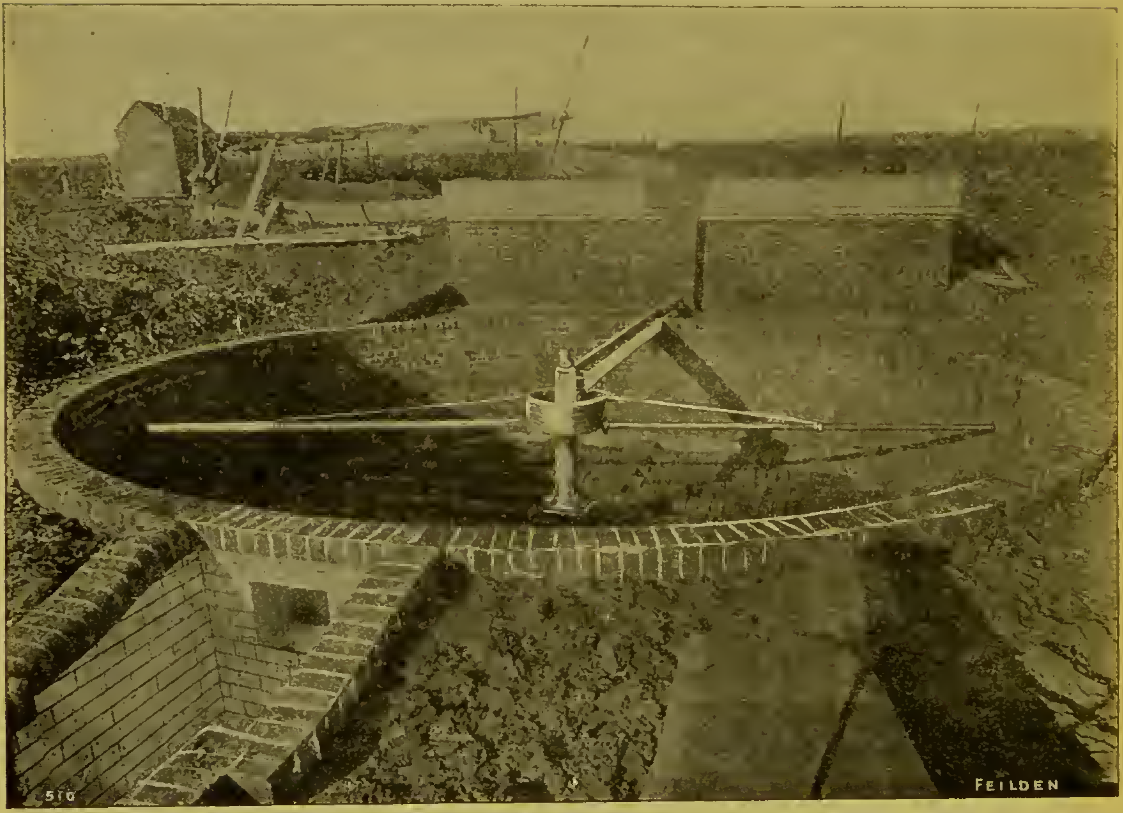

FIG. 45.—CANDY-CAINK SPRINKLER BEFORE THE BED IS FILLED.

Continuous and intermittent filtration, apart from the differences between the results obtained, present a contrast both in the mechanical arrangements and in the bacterial process itself.

In the case of contact beds, except when they are used in series, there is no differentiation of the organisms in relation to the food supply, because, although the conditions are changed from being purely anaerobic to those more or less favourable to aerobic action, these are conducted in such a way as to provide neither condition continuously, and the results obtained have already been dealt with and explained in previous chapters.

When an apparatus is designed from the point of view of overcoming these objections, it is obvious that the methods of bringing about the contact between the sewage and the bacterial surfaces must be radically different.

One of the most generally recognized facts in connection with the filtration of hydrolysed effluents is that whenever there is a continual dripping upon a particular spot, growth occurs of a filamentous character allied to Crenothrix, rapidly disappearing on exposure to the air after the dripping has ceased. This points to the necessity of very highly aerated conditions upon the upper services of filters, to prevent their being clogged up, and rendered ineffective. It has been found that if a sufficient time is allowed to elapse between the discharges of liquid, on the upper surfaces, that this filamentous growth is practically got rid of altogether, and moreover the action of the fluid passing through the filtering material intermittently must have something in common with the action of the lungs, which are cleared out between each breath.

In the Ashtead experiments (p. 222) it was found that the best results were obtained from a discharge occurring about every 7 minutes, and that this method of administering the food supply to the organisms avoided all those growths which are susceptible to rapid destruction by exposure to the air. The best all-round results were obtained when the quantity of liquid per unit of filtering area of the top surface was limited to one gallon per square foot per hour, which gives a total of a little over 1,000,000 gallons per acre per 24 hours. These rates of flow and period between each discharge, when the filters were divided into trays each 7 inches deep, and nine in number, were those which gave the high nitrates in the effluent referred to in p. 224, when the ratio of oxidized to unoxidized nitrogen reached to as high as 96·7 per cent. As this quantity of nitrates had never been approached before, it becomes a matter of great importance to repeat the same conditions as regards accuracy of distribution, rate of discharge and periods of rest between each discharge on a large scale, if this can be done satisfactorily and economically.

The apparatus used at Ashtead for the distribution referred to consists of V-shaped trays automatically discharging their contents when the liquid reaches a level which upsets their equilibrium. They are hung on small trunnions, fixed at the proper points to effect this movement, working upon supports at each end. These are shown in the illustration (fig. 46), and are now being used for small installations, such as country houses, public institutions, etc.

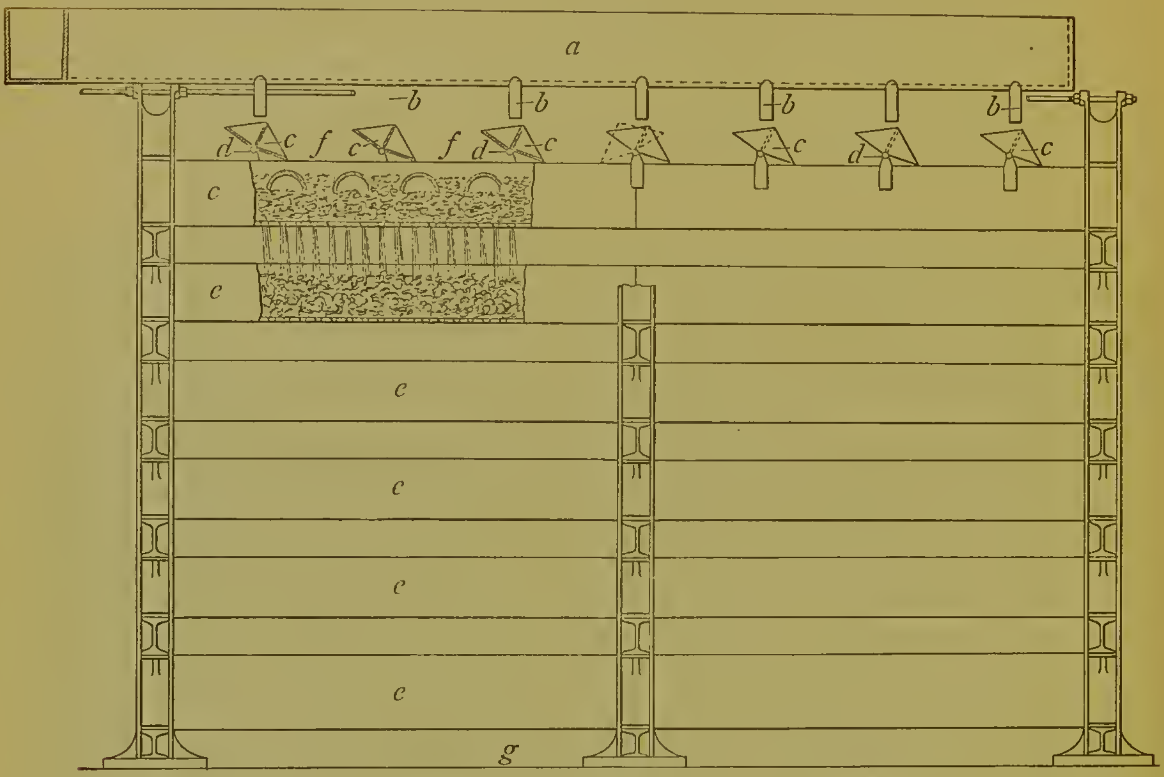

FIG. 46. SECTION OF MONCRIEFF TRAYS AND TIPPERS.

If the above conclusions are justified,—and there is no reason to suppose that they are based upon any wrong data,—we have a standard with which to compare other distributing appliances constructed with the same end in view.

A revolving sprinkler is open to the objection that the periods between the discharges, being measured by the revolutions of the double arms, are not only far too short, but are also irregular, because although the angular velocity of the arms is the same at every unit of distance from the centre, the flow near the centre must be greatly in excess of that which takes place at the perimeter of the circle described, per unit of surface covered. To a certain extent the fault may be remedied by increasing the size of the holes towards the exterior. At Caterham, even with

Sewage Distributor for Bacterial Percolation Beds.
Efficiency 500,000 gals. per 24 hours.
Fan efficiency 20,000 cub feet of air per minute.

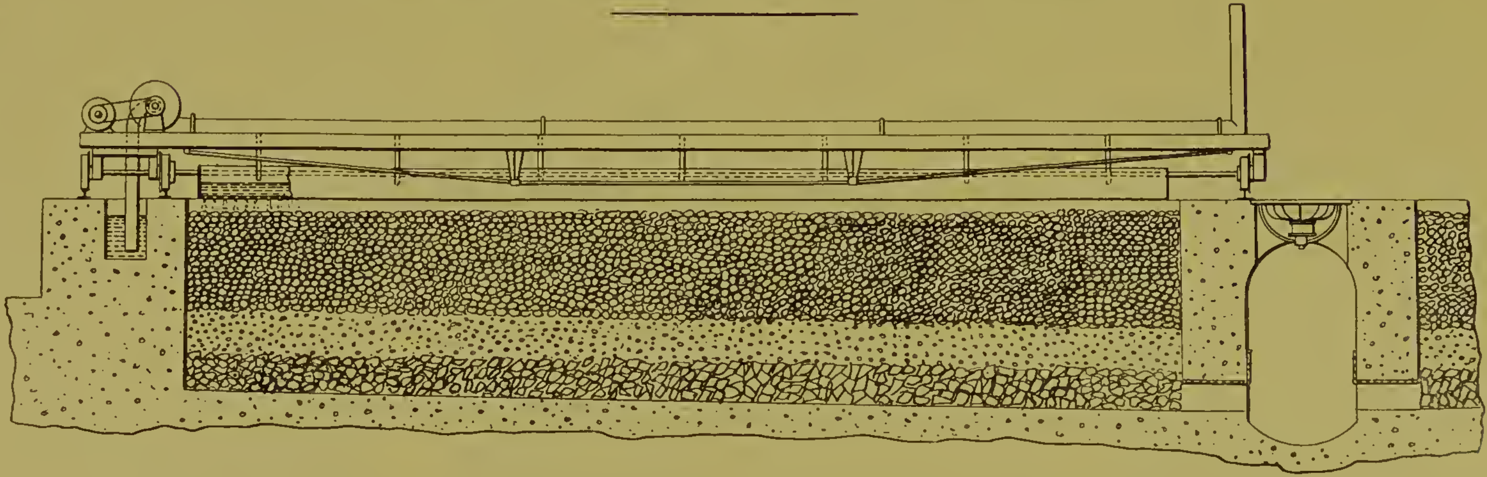

FIG. 47. MOVING DISTRIBUTOR FOR AN ACRE FILTER BED (MONCRIEFF).

this modification, revolving sprinklers are stated not to have fulfilled the required conditions, with the additional difficulty of the choking of the holes already mentioned.

Other methods have been tried, by placing over the upper surface of the filters perforated plates with large tilters, throwing the liquid at proper intervals, but these have proved to be less accurate than the tippers described. Of course an intermittent flow at any desired period between each discharge can be obtained from automatic syphons attached to tanks, which fill to a certain point before discharging, but if the flow from these tanks is carried through pipes, an irregularity occurs in the distribution, due to friction of their internal surfaces.

For large scale distribution Mr. Scott-Moncrieff has recently designed a novel apparatus for carrying a supply pipe fixed upon small trucks or bogeys on each side of the filter beds, which are constructed with a length greatly in excess of their breadth. He suggests that a convenient unit of filtering area dealing with 1,000,000 gallons per 24 hours should have a length of 500 yards, with a breadth of 30 feet. Along each side of these beds he constructs channels receiving the flow of the hydrolysed sewage continuously, the liquid being delivered to the travelling distributing pipes either by means of syphons or by a small turbine or other suitable pump, worked by an electric motor upon one or both of the travelling bogeys which carry the pipe. This apparatus (fig. 47) has the same advantages as the one already referred to, and regulates the ratio of air supply to volume of sewage on each unit of filtering surface. By means of a fan or exhaust at the bottom of the filter bed, a further control on the volume of air can be obtained.

TRADE EFFLUENTS.

A. *In relation to Chemical and Precipitation Processes.* Where land or precipitation is solely relied on, trade effluents are a source of great difficulty. Thus it is reported from a town in the north that "they had six times the ordinary flow of sewage, owing to brewery refuse. Consequently complaints were very numerous, and they had to reconstruct their sewers and get a farm of 500 acres, at a cost of £250,000. Wherever they had a staple trade they could not rigidly enforce the law, and they frequently had water discharged into the sewers at 212° F." An example of high pollution of another kind is given in the report of the city of Worcester, Massachusetts (population 70,000), Nov. 1899, where the amount of copperas from pickling liquors discharged reached 64½ tons per day,* requiring an enormous quantity of lime for neutralization, averaging over half a ton per million gallons sewage, and producing a voluminous sludge, containing as usual, after sedimentation, about 98% of water, reduced by filter presses to 60 or 70%. By the chemical precipitation, which seems in this case to be inevitable, about 90% of the suspended impurities are removed, "and a very small percentage of that in solution," the total purification being 54% of the organic matter, carried to 99% by subsequent intermittent filtration through 6ft. of sand, when the effluent is said to be "purer than the river-water itself," a generally superfluous degree of improvement.

In the Local Government Board Inquiry at Nuneaton, on Dec. 29th, 1899, it was recorded that their local proportion of trade discharges to sewage proper was :—

Fellmongers	100,000	gallons	per day
Woolscourers	10,000	,,	,,
Hat factories	20,000	,,	,,
Ordinary sewage	370,000	,,	,,
Total	500,000	,,	,,

that is, that the trade discharges were 26 per cent. of the whole volume. The evidence stated that "one-third of the present sewage is now treated by the bacterial system, and the sewage of the town lent itself to this treatment. . . . . The particular trades dealt primarily with their sewage, and the quantity of grease which was at one time perceptible was now considerably reduced." Especially in the North of England, processes for treatment of factory waste-waters on the works themselves have been greatly improved, and in a large number of cases made remunerative by recovery of products. Mr. Tatton, inspector to the Mersey and Irwell Board, classifies these liquors into those from (1) print works, (2) dye works, (3) bleach works, (4) waste bleach works, (5) paper mills, (6) paper stainers, (7) tanners and leather dressers, (8) fellmongers, (9) woollen trades, (10) silk trades, (11) coal slack washers, (12) soap makers, (13) stone polishers, (14) chemical manufacturers, (15) brewers, (16) unclassified.† In the majority of works the discharges are dealt with, after screening, by precipitation with iron and lime. As mentioned in Chapter VII., a *ferric* salt is found to be more effective than a ferrous salt (copperas).

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* Equal to 120 parts per 100,000, or 0·12 per cent. See the remark (p. 265) as to a soap-works effluent.

† *Purification of Water after Use in Manufactories*, by R. A. Tatton, M.I C.E., *Proc. Inst. Civ. Engineers*, Jan. 9th, 1900.

Mr. Tatton gives typical examples of the methods adopted in large factories in the watershed, from which we extract the following particulars—

I.—*Bleach, Dye, and Finishing Works*, Cheadle. Logwood and aniline dyes with mordants. The whole is treated with milk of lime by a trough and mixer, thence passes through screens into a long channel in which blocks of iron alum (ferric ammonium sulphate) are suspended and gradually dissolve. Traversing three tanks, where a large amount of sludge is deposited, the partly clarified water is pumped into a series of high-level tanks holding 9000 gallons each, iron alum being again placed in the inlet channel. Each tank requires 3 hours to fill; 5 or 6 hours is allowed for settlement. The clear liquid is drawn off by floating outlets, and passes on to filters composed of six inches of fine ashes and 12 inches of rough clinkers with 4in. tile drains below, whence it is discharged into a brook. "The effluent is clear, and of a pale straw colour which is imperceptible in the brook a few yards from the outlet."

The sludge from the various tanks was formerly deposited in lagoons, but the quantity was so great that filter presses became a necessity. The sludge presses well without adding any more lime, and the solid cake is removed to a tip. The settled sludge contains 95·6% of water, and the pressed cake 71·4 (average of 12 samples). Cost of works £6000; annual expenses £530. Number of hands in mills 210; in purification works 4. Volume of liquid treated daily 300,000 gallons, rising occasionally to 500,000.

II. *Flannel and Dye Works*, near Rochdale. An example of "the most complete and elaborate arrangement to be found in the watershed for dealing with this kind of waste," and pronounced to be very effective.

Treatment of Soapy Water from the Scouring and Finishing. The liquid first passes through a fine copper sieve to remove wool fibres: the sieve is cleaned by a revolving brush, and the flocks of value collected. It is then mixed by a water-wheel with milk of lime, afterwards with a solution of ferric chloride 12 feet further on, next passes through five settling tanks (arranged so that any one of the first three can be thrown out for cleansing, and each provided with scum-boards), on to two filters of fine ashes, used alternately, thence into the streams.

The sludge is treated with sulphuric acid to break up lime soaps, and pressed through cocoa-nut matting, the acid filtrate being used again. The sludge cake is further pressed to recover oil, various products from which are made and sold ; the refuse is burnt.

The *Dye Water* after screening, scumming, sedimentation, and filtering through ashes, is discharged into the stream. No precipitation is mentioned. Alizarine dyes only are used, which are almost completely absorbed by the wool, and leave little solid matter in suspension : the bichromate liquors are pumped into the boilers for preventing scale : "no other boiler composition has been found necessary, and the valves have lasted better than previously."* Total volume of water used, 180,000 gallons per day ; cost of purifying works, £1970 ; nett expenditure on treatment during 1898, £199 16s.; number of hands in mills, 90.

In a large number of woollen mills, simpler works have given excellent results. They consist of "Sap-tanks," in which the water from the scouring processes, which contains most of the grease, is treated with acid and the grease recovered, also precipitation tanks and filter-beds.

III. *Calico-Printing, Dye and Bleach Works*, Chadkirk. Alizarine and aniline dyes, logwood and other extracts, soap, starch, fustic, soda, bleaching powder, etc. The whole trade waste and wash waters are collected together in a detritus tank, which is cleaned out weekly. The liquor then flows through a settling tank, past screens with blocks of iron alum, into either of two precipitation tanks of about 180,000 gals. capacity, taking 2½ days to fill, and 2 days to settle. Floating outlets draw off the liquid, which then undergoes a double filtration through 12 inches of stones, 12in. clinkers, and 18in. fine ashes on top.

Contrary to the experience of some dye works, the filters make a great improvement, although lime does not appear to be used. The sludge is run on to ground by the Mersey, and when dry, is spread on a grass field adjoining. The precipitation tanks are cleaned out after every filling, the settling tank every three months. Total volume, 190,000 gallons daily ; cost of purifying plant, £650 : annual, £149 ; hands in works, 195.

IV. *Recovery of Waste Products* at a print works on the Mersey. Soap liquor is treated with lime and iron alum, pressed, the cake steamed with acid, the grease separated, and the acid and alum from the press-filtrate used again. The grease is stated to be worth at least £7 per ton, but even at £4 10s. it pays the whole of the expenses of recovery, the quantity being 15 to 20 tons a year.

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* It is usually more profitable to recover the bichromate by precipitation

"The separate recovery of indigo is profitably adopted now at all large works. In this factory, about £1200 a year is recovered on £4000 worth of raw material. Wash waters are precipitated with alumino-ferric and caustic soda, and the solids, with the vat sediments are treated chemically to separate pure indigo.

Logwood liquor is difficult to treat, and contains much solid matter, hence is separately precipitated, though the product is at present valueless, even for manure, as it generates fungus ; it is simply pressed and burnt.

For the general precipitation with iron-alum and milk of lime (added 20 yards apart in the culvert), the tanks at these works have a capacity of 413,000 gallons and an area of 22,000 square yards. The accumulation of solids in the tanks is not great, and the filters require the surface renewing only once in four months. The surface lasts longer when it has been in use for some time than when entirely new, *suggesting a biological action, as with sewage.*

Cost of tanks and filters £1,500 ; maintenance £60 per annum : the three recovery plants pay for themselves with a good profit. Total volume treated 500,000 gallons daily.

An interesting point is that a considerable saving is also effected in materials by the necessity for preventing pollution of rivers. Formerly, if a mixing was wrong it was sent down the drains into the river, now it has to be taken to the tip and the error is detected."

One of the most polluting liquids is the water from the kiers in which cloth, rags, esparto, and straw are boiled—a strongly alkaline fluid which alone is difficult to treat. Judicious mixture with acid liquors and precipitation are used, while at one works carbonic acid is forced in to reduce the caustic alkalinity.

The grease from wool is peculiarly intractable, owing to the partial replacement of the glycerin of ordinary fats by *cholesterin*, $C_{26}H_{43}(OH)$, a solid insoluble alcohol with a distinct affinity for water, insoluble in alkalies and in acids except concentrated sulphuric. The cholesterides show a remarkable adhesion to water, not rising to the surface like ordinary fats, but remaining suspended. Ferric sulphate, with lime, will carry down the greater part mechanically, giving a sludge difficult to press (p. 138), and containing about 25% of grease ; moreover, an inordinate amount of chemicals is required.

The wool-grease, when purified, has attained a special commercial value as "lanoline," hence its extraction has received much attention. The perspiration of sheep, or "suint," contains in addition considerable quantities of *potash*, which also pays for separation along with the alkali from the potash or soft soaps which are used for scouring. At Bradford, the grease is now recovered at some of the larger factories, and it is suggested* that the smaller firms could combine and convey their suds by pipe sewers to one or more centres, where they could be dealt with in a wholesale manner. It is clear that this suggestion of co-operative treatment might be applicable to other trades whose works were not too distant. Besides the general methods of dealing with soapy liquors (p. 122), several special processes are used in connection with wool.

I. *Degreasing.* Treatment with volatile solvents, such as bisulphide of carbon, benzene, or light petroleum in an apparatus similar to Leuner's, used for degreasing bones ; the fat is thus extracted almost unaltered, and the solvent used again. At present this method has not been found commercially successful.

II. *The Ayrshire Process* (Biggart & Co., Dalry) is specially applicable where certain classes of wool and potash soaps only are used. The suds after depositing sand, etc., are evaporated to a syrup, when the unsaponified grease separates, and is removed at intervals. The residue is calcined, and yields a crude carbonate of potash, which is either dissolved and used again for scouring, or refined, when it sells at £16 10s. per ton. The grease is boiled with sulphuric acid, and may be sold at about £6 per ton, or purified further. The process is said to be worked at a profit.

III. *Ordinary or Sulphuric Acid Process.* When the suds are treated with sufficient acid to decompose the soaps, the grease and fatty acids rise as a scum and are collected and filtered, pressed hot, and sold as "Yorkshire Brown Grease."

IV. *Mechanical Process of Motte & Co.*, Roubaix, France. The suds are agitated by beaters, raising a froth which carries to the surface the globules of insoluble fats, this is skimmed off by travelling scrapers and heated to 60°C with one-thousandth of sulphuric acid to clarify and separate it. The grease is strained through canvas bags, and the refuse is sold as manure. The acidified effluent is precipitated by lime, and is then said to be neutral and perfectly clear.

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* *Borough Surveyor's Report*, Bradford, September, 1896.

V. *Lagerie Process*, Roubaix. In France and Belgium and in a few cases in England (as at Alston Works, Bradford), the potash and much of the organic matter is extracted by hot water from the wool before scouring, and the liquor evaporated and calcined as above.

Silk Works. The gummy character of the wash-water renders it difficult to deal with, but at Lister's Works, Bradford, according to Baldwin Latham, a double precipitation produces an effluent fit to be used again in the factory, at a cost not exceeding 6d. per 1000 gallons.

Paper Works. The process must vary with the materials used. Caustic liquors from esparto or straw are evaporated and the soda-ash recovered by incineration. The wash waters are economized by being used over and over again and finally are precipitated and filtered as above. Wood-pulp works introduce much less pollution : the whole of the pulp, which is usually prepared abroad, is of value, and is kept back by a variety of " save-alls " (revolving sieves of fine gauze), and settling tanks.

At Dartford Creek Paper Mill, Kent, a patented apparatus is in use which is intended for purifying trade effluents generally. It consists of a series of closed sediment chambers followed by a closed filtering chamber in compartments charged with coarse or fine ashes, the liquid being forced through the whole arrangement under pressure. Each settling chamber has a hopper-like bottom with a sludge-cock for withdrawing the deposit. The ashes are contained in receptacles fitting closely into the filtering compartments, so that they can be withdrawn when clogged and fresh ones substituted.

Bleach Liquor and its persistence have been alluded to at p. 149. Chlorine in the free or oxidized state is not removed by ordinary precipitants, except ferrous sulphate : in a hydrolytic tank it would at once react with the ammonia and sulphuretted hydrogen as at p. 146, and unless in undue proportion to the rest of the sewage would be rendered innocuous.

Tanners' and Fellmongers' Waste is generally admitted to the sewers after deposition of the grosser solids. If precipitation is practised, the tanks require to be cleaned out frequently in warm weather, and suitable land or double filtration is resorted to afterwards.

Breweries. A large quantity of water is used for cooling ; this does not require treatment. The washings of barrels, vats, and tanks are precipitated and filtered, but in many breweries they are discharged direct into the sewers.

Slack-washing, practised at some collieries for separating small coal, gives a water which readily clears in settling tanks, and can be used again and again.

Chemical works give waste water of so various a character that each case must be decided separately.

In a number of experiments on trade effluents, Meade-King* found that the addition of salt water greatly helped the precipitation, either by iron alum, which he considers the most useful precipitant, or by tannin (from oak bark, leaves or galls), which is specially useful in gelatinous effluents like those from print works.

Local Regulations.—Under Section 7 of the Rivers Pollution and Prevention Act, 1876, every Sanitary Authority having sewers under their control shall give facilities for enabling manufacturers' liquids proceeding from their factories to pass into the sewers, provided that nothing injurious is so discharged. In the West Riding Act, 1894, any liquid rendered poisonous, noxious, or polluted in the course of some manufacturing process, must be excluded. The Bradford Act of 1897 states that it shall not be lawful for any person to cause or suffer any refuse from any manufacturing work, that would interfere with the treatment or utilization of the sewage of the city, to flow or pass into any sewer or watercourse. The London County Council General Powers Act, 1894, section 10, provides for the prohibition of the discharge of dangerous substances into sewers. In view of an explosion that had occurred, an order was served in July, 1899, prohibiting "any petroleum or any product of or residue from petroleum or any liquid or substance giving off, or liable to give off, inflammable vapour, being caused or permitted to fall, flow, or enter, or to be carried into any sewer directly or indirectly." At Bilston, nothing is admitted into a sewer "which would either damage the sewer or the living crops," (irrigation), and the authorities have the additional power to exclude anything which could injure the purification process which might be in practice.

At Bradford, under the above Improvement Act, the Corporation have the power of preventing manufacturers from discharging untreated trade effluents into the sewers, with a payment, in certain cases of prescriptive rights, of a compensation for expenses of purification. A single firm at Bradford is stated to recover from the suds one ton per day of "oil grease," valued

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***Proc. Inst. Civ. Engineers*, Jan. 9th, 1900.

at £12 10s. per ton, while no attempt is made at recovery from the 11 tons per day of grease and dirt washed from the raw wool. From this, according to Mr. Blount, at least 5 tons of grease worth £6 per ton per day could be obtained at a cost of about half the value. Mr. Cox* estimates that 370 tons of greasy wool are washed per day in Bradford, which "corresponds with a net income of £58,275 thrown away in such a manner as to be not mere loss, but a positive injury to the town in that it interferes with the proper treatment of its sewage."

B. In relation to Bacterial Processes.—At Local Government Board inquiries it is constantly asked whether manufacturing effluents will interfere with bacterial treatment.

On the whole, the effect of these liquids has been greatly exaggerated. In the case of small settlements collected round factories, the domestic products may be only in small proportions, and the effluent must be treated specially by chemical methods and not as a sewage proper. In large towns these discharges are usually so largely diluted that they cannot interfere with a bacterial process when rightly carried out.

It has been said that the antiseptic action of some chemicals would arrest the bacterial changes. But by actual cultures it has been shown that the amount of disinfectant required to kill or even inhibit the organisms is far in excess of what can be present in the mixed sewage. For example, at Yeovil, where arsenic as sulpharsenite of calcium is derived from the refuse of glove-making, I found that the maximum quantity of orpiment, As_2S_3, that could enter the sewers per week, if the whole amount escaped, was 2 cwt., equal in 120,000 gallons of sewage daily to 3·9 parts of As_2O_3 per 100,000, or ·0039 per cent., whereas Miquel observed that 0·6 per cent., or 600 parts per 100,000 of As_2O_3 was required to prevent bacterial growth, and Frankland and Ward assert that it has little effect on lower forms of life.

In December, 1899, I examined the waste liquors from two of these factories, and found:—

Arsenic (As) parts per 100,000	6·86	9·45
Equal to arsenious acid As_2O_3... ...	9·0	12·48
Total bacteria per cc.	16,900	3,300
Rapidly liquefying ditto	7	100
Spores	100	1,000

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*Sanitary Congress, Leeds, 1897.

Therefore, although arsenic in this quantity has an inhibitory effect on some organisms, the liquid still contains a large number, including those of a rapidly liquefying character, and spores, so that the bacterial work would not be arrested, even if the liquid reached the tanks undiluted with sewage or storm-water. In comparative trials with the sewage alone, and mixed with $\frac{1}{12}$ of waste liquor, I found that both denitrifying and nitrifying changes proceeded similarly with either. As a matter of fact, the total volume of trade liquors in the Yeovil sewage on any one day does not exceed one-fortieth of the estimated dry-weather flow.

As an instance of an acid effluent, I found that a soap works at Exeter was discharging ½-ton of acid liquor daily. Even if this contained 1 per cent. of sulphuric acid, it would amount on a million gallons of sewage to 0·1 part per 100,000. But crude sewage has sufficient alkalinity to neutralize more than this amount of acid provided the latter be not supplied in spurts as when poured direct on a filter. I have already remarked on the beneficial mixing and "smoothing" effect of the septic tank on the great fluctuations that occur at different times in all varieties of sewage. I believe that the same natural neutralization and precipitation would dispose of most metallic admixtures such as iron salts, galvanizing pickle, etc.

With regard to tanning refuse, the antiseptic power of tannin itself is very small, and moreover, it does not pay to let much of it escape. At Exeter I estimated the daily quantity from the large tannery in that town as equivalent to that in six fluid ounces of brewed tea per head of population, and it certainly could have no influence.

Effluents containing animal or vegetable matters, either suspended or in solution, as those from breweries, starch factories, etc., however foul and unfit to be discharged into rivers, present no difficulty to bacterial treatment, as the large numbers of liquefying bacteria which they contain contribute to the efficiency of the process.

Popp and Becker* found that "liquefying bacteria" were killed by 0·5% of sulphuric acid or by 1% of sodium carbonate, an acidity or alkalinity that would be higher than the ordinary factory runnings, and would be brought down when mixed with the whole of the sewage to an unimportant factor. As an example I ascertained that at a certain paper mill 35lbs. of soda-ash were used daily: the maximum addition to the alkalinity of the whole daily sewage was 0·3 parts per 100,000 or ·0003°/$_o$.

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* Chem. Hyg. Inst., Frankfort, 1896.

Gas liquor and the effluents from timber works often contain a large quantity of suspended tar, which clogs up filter beds and presses, and fouls the catch-pits and sewers. Therefore they must usually be excluded. A sample of refuse from a timber yard which I examined in May, 1899, contained, in parts per 100,000 :—

Heavy petroleum	1560
Pieces of wood, straw, leaves	210
Earthy matter and oxide of iron	827
Solids in solution	33

This is an example of discharges that are easily dealt with by a catch-basin and straining, as the filtrate was nearly clear, almost inodorous, neutral, and not injurious to bacteria. Without such treatment the floating tarry film might possibly somewhat hinder the activity of the upper bacterial layer of a septic tank, but the aqueous liquid itself in its dilution would not be likely to interfere either by its sulphides, cyanides, ammonia or tar-acids, inasmuch as many bacteria generate and live in a medium impregnated with ammonium sulphide, while cyanogen compounds are far less poisonous to lower organisms than to higher animals, and the strongest of the tar derivatives are not bactericidal under 0.5%, or 500 parts per 100,000,—an impossible amount to be present in the mixed sewage.

In exceptional cases, however, where intense acidity or other strong admixture cannot be avoided, the use of lime and a settling tank would become necessary: in this case a sludge would be created which would not be that of sewage.

Dr. Bostock Hill* stated that the sewage of Wolverhampton "heavily polluted with chemicals," and that of Lichfield with "a large amount of brewery refuse," did not interfere with the Garfield coal filter which was working bacterially.

Mr. Fowler reported at Davyhulme, Manchester, in September 1898, in reference to the bacterial filters of coke-breeze, that :— "With regard to trade refuse ; iron pickle (ferrous chloride), dye refuse, carbolic acid, and sulphocyanides from gas liquor, are all removed or oxidized, that 'in no case has the presence of manufacturing refuse showed a marked tendency to make the purification less effective,' though 'it is probable that with purely domestic sewage the yield of nitrate would be larger.'"

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*Leeds Sanitary Congress, 1897.

Fibrous matters, such as those from wool manufacture, and from horse-dung and wood-pavements, as mentioned in Dr. Clowes' L.C.C. Report of 1899, seriously interfere with the action of the bacterial filters, but are easily dealt with by hydrolysis in a septic tank.

In conclusion, I believe that a bacterial process, conducted in regular sequence, would deal with all ordinary manufacturing admixtures.

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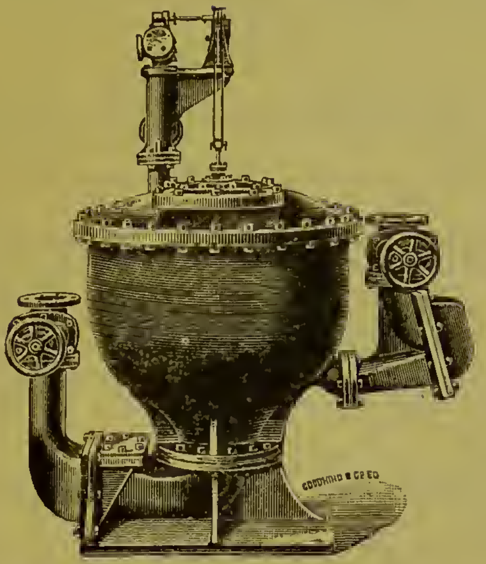

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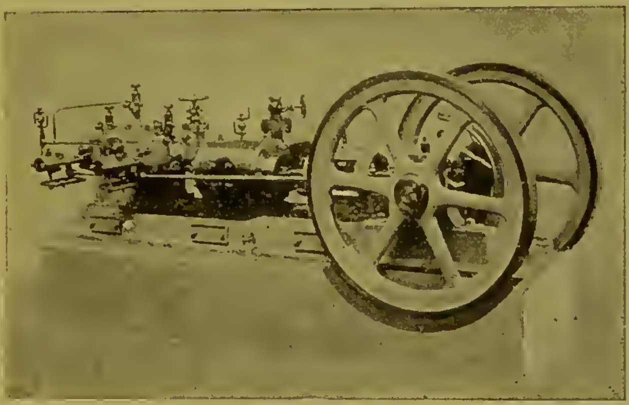

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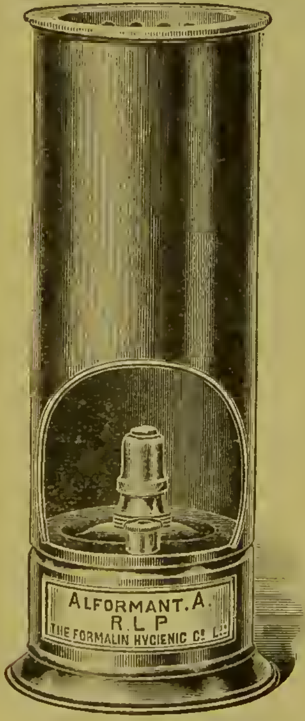
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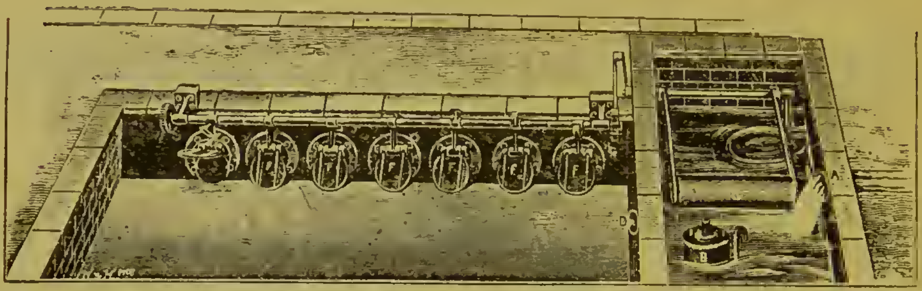

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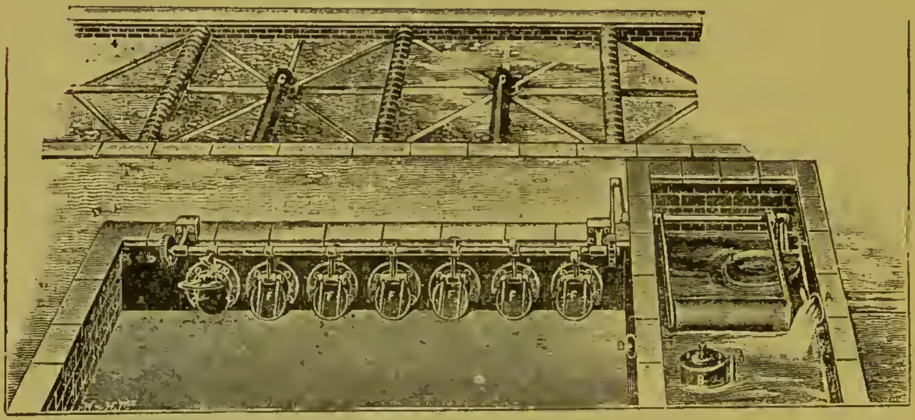

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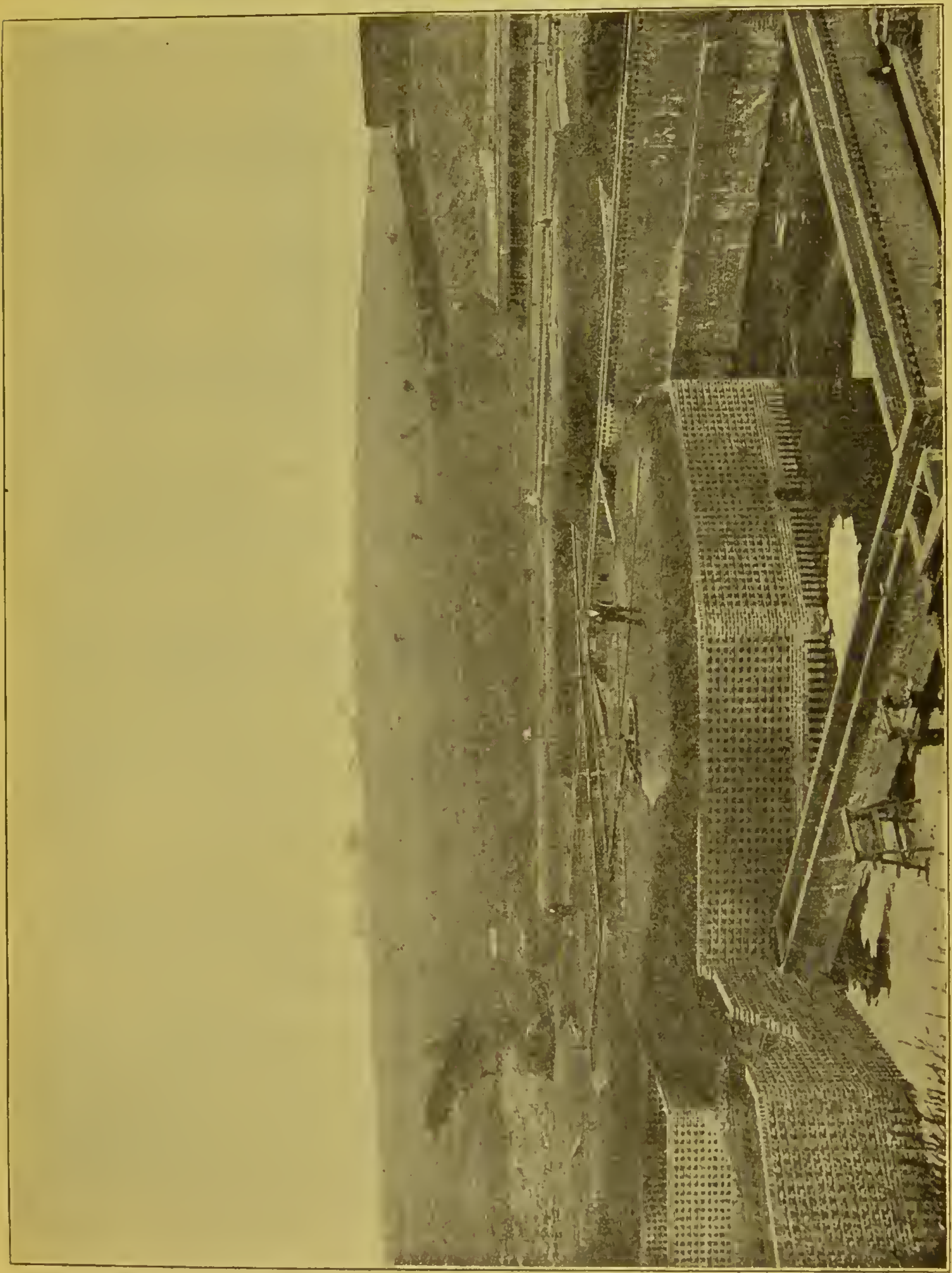

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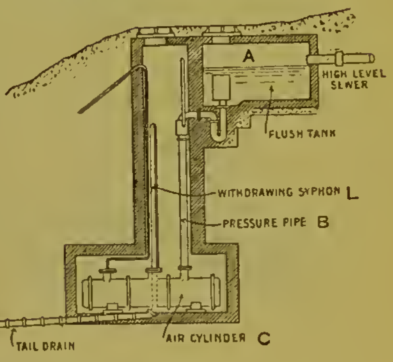
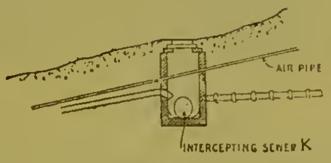
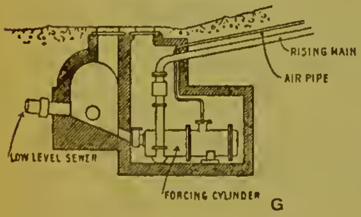

A
HIGH LEVEL SEWER
FLUSH TANK
WITHDRAWING SYPHON L
PRESSURE PIPE B
TAIL DRAIN
AIR CYLINDER C


AIR PIPE
INTERCEPTING SEWER K


RISING MAIN
AIR PIPE
LOW LEVEL SEWER
FORCING CYLINDER G

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