THE
PURIFICATION OF SEWAGE

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BEING

A BRIEF ACCOUNT OF
THE SCIENTIFIC PRINCIPLES OF SEWAGE PURIFICATION
AND THEIR PRACTICAL APPLICATION

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PREFACE.

In the present volume—a small book upon a large subject—the question of the Purification of Sewage is dealt with chiefly from a chemical and biological point of view, and in the light of the experience gained in the discharge of my duties as the Medical Officer of Health of a large County. That office has afforded me constant opportunities for the inspection of sewage works in actual operation, and for analyzing the effluents from such works. As the result, I have endeavoured to set out in these pages as succinctly as possible, and yet (it is hoped) with sufficient fulness for the purpose in view, the conditions which appear favourable for particular processes for the purification of sewage, and their necessary limitations.

Until the passing of the Local Government Act, 1888, by which County Councils were constituted, the enforcement of the Rivers Pollution Prevention Act of 1876 was left in the hands of the Sanitary Authorities, who, being themselves the chief offenders against the provisions of that enactment, were, naturally enough, very loth to institute proceedings against one another.

Now, however, under pressure from County Councils and Joint River Boards, the District Councils are seriously taking in hand the work of saving our rivers and streams from pollution, and the question is constantly being asked, "What is the best process of sewage purification to adopt?" The form of this question shows only too clearly that the real nature of the problem is not generally understood. It is, indeed, of the first importance that members and officers of the various bodies, upon whom devolves the duty of dealing with the problem of purification of sewage, should grasp the scientific principles of the question, and recognize the fact that the particular scheme to be adopted in any locality must depend upon a variety of local circumstances. It is with the view of giving some help in this direction that the following pages have been written.

During recent years, by means of numerous bacteriological and chemical investigations, both in this country and in America, great advances have been made in our knowledge of the changes which sewage undergoes in purification, and not a few conclusions of wide-reaching importance established; and it is hoped that the presentation in this little work of some of the results thus attained will be found useful by engineers and other officials who wish to avail themselves of the latest researches of chemists and biologists upon the question of Sewage Purification.

SIDNEY BARWISE.

COUNTY OFFICES, DERBY,
October, 1898.

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THE PURIFICATION OF SEWAGE.

CHAPTER I.

SEWAGE: ITS NATURE AND COMPOSITION.

Definition of sewage—Sewage from water-closet and non-water-closet towns—Plea for the general adoption of water-closets.

By "sewage," which is derived from the Anglo-Saxon "seon," to flow down, is meant the liquid contents of a sewer. This, in its simplest form from a village or non-water-closet town, is frequently designated "slop-water." It contains the liquid excretions of the inhabitants; the foul waters from the kitchens containing vegetable and animal matters, bits of fat, and other refuse; the "suds" from the washing of dirty linen, cooking utensils, and the people themselves, holding in solution and suspension soap, fatty acids, and the exudations from the human skin. Such soapy slops, as every one is aware, if allowed to stand for twenty-four hours, become most foul and offensive. Then there is the dirty water from the washing of floors, the swilling of yards, the solid and liquid excretions of animals in the streets, the drainage from stables and pig-sties, the blood and other animal matters from slaughter-houses, silt from street sweepings, and sometimes, if the town is an old one, the most offensive and concentrated filth of all, the soakage from a privy-midden. From a consideration of its various constituents, I think it must be admitted that even what is called "slop-water" is a polluting noxious liquid, no less offensive than ordinary sewage.

In the case of water-closet towns, in addition to the above polluting matters, there are the solid excreta from the inhabitants, paper and other matters of a like nature emptied through the closets into the sewers, but there is also a larger amount of clean water. As a rule, in both cases, the surface water from the streets and from the yards, and a certain amount of ground water, finds its way into the sewers.

Sewage as defined is the liquid contents of a sewer, and as a sewer has a specific meaning under the Public Health Acts, the definition of this word becomes a point of great importance, involving, as it does, an answer to the question, What is sewage?

By sect. 4 of the Public Health Act, 1875, a "drain" is defined as meaning any drain of and used for the "drainage of one building only," or premises within the same curtilage, and made merely for the purpose of communicating therefrom with a cesspool or with a sewer; whilst "sewer" includes sewers and drains of every description, except those to which the word "drain" interpreted as above applies. From this definition it follows that where two or more houses have a common drain, that drain is, within the meaning of the Public Health Act, 1875, a sewer, and as such, by sect. 13 of the same Act, it is vested in the Sanitary Authority, who become, by sect. 3 of the Rivers Pollution Prevention Act, 1876, responsible for using "the best practicable and available means to render harmless the sewage matter" falling or flowing therefrom into any stream or watercourse.

The importance of this definition can hardly be exaggerated, and numerous cases have arisen on the point. The decisions of the Court of Appeal, however, have made it quite clear that where two or more houses drain into a common channel, whether that channel be a pipe-drain, or even an open ditch,* it is a sewer, and the Sanitary Authority are liable for its maintenance in such a state as not to be a nuisance, to keep it properly cleansed, ventilated, and repaired (sects. 15 and 19 Public Health Act, 1875), and to use the best practicable and available means to purify the sewage flowing from it.

Sewage is an extremely complex fluid, varying in the same place from hour to hour both in its volume and in its chemical composition, nor is the sewage

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* *Wheatcroft* v. *Matlock Local Board*, 52 L. T. (N.S.) 356.

of any two places the same, even though it be in each case of a purely domestic character.

Dealing first of all with the sewage from non-water-closet towns: the greatest cause of its variation is the quantity of water per head supplied to the district. It is frequently supposed that this sewage is not of such a polluting nature as that from towns where the water-carriage system has been adopted. Although the total amount of sewage matter conveyed to the outfall by the sewers is greater where water-closets are in use, yet the average composition of such sewage is no stronger than that from towns where there are no water-closets. The reason for this is that water-closets are not generally used except in towns where there is an ample water supply; and although it is true that by the general adoption of water-closets two and a half ounces of excrement per head per day, containing 25 per cent. of solid matter, are added to the sewage, yet the water which is used for flushing, and the unavoidable waste which results from the adoption of the water-carriage system, are sufficient to dilute this five-eighths of an ounce of solid matter below the strength of average sewage from a non-water-closet town.

With regard to the sewage of water-closet towns, the chief difference is that it contains a larger amount of suspended matter, such as disintegrated paper, the filaments of which are liable, if not removed, to form a film of papier-maché on the surface of sewage filters. In the manufacturing towns there is also more or less refuse from factories draining into the sewers.

By sect. 7 of the Rivers Pollution Prevention Act, 1876, every sanitary authority is compelled to give facilities for enabling manufacturers within its district to carry the liquids proceeding from their factories into the public sewers, provided that such liquids do not prejudicially affect the sewers or the system of disposal of the sewage, or are not from their temperature or otherwise injurious from a sanitary point of view. The chief manufacturing processes which produce liquid wastes, that manufacturers may ask facilities for draining into the sewers, are brewing, paper making, bleaching, calico printing and dyeing, wool scouring, fulling and felting, tanning and fell-mongering, and chemical and alkali works. Some of these wastes if admitted in a reasonable proportion are advantageous, while other, such as galvanizers' pickle, may, unless special precautions are taken, be injurious to the sewers, and also to the system of sewage disposal.

Where manufacturing wastes are admitted into the sewers, arrangements should be made for their admission evenly and continuously. It is no uncommon thing to see the sewage of a manufacturing town completely change in its appearance and composition several times in the course of an hour, defeating all attempts at purification.

Water-closets.—The sewage from water-closet towns is no stronger than ordinary sewage or slop-water, which is a polluting liquid necessitating purification works whether the excreta of the inhabitants are added to the sewage or not. This being so, the advantage of adopting water-closets is apparent. The alternatives are the pail system or some form of privy-midden.

With regard to the pail system, the cost of emptying a pail weekly is on the average about eight shillings per annum per house, or twopence a week. On the other hand, if water can be obtained at eightpence a thousand gallons, the cost in water for each house is about four shillings per annum.

As for the midden system, it is now too late, at the beginning of the twentieth century, to contemplate a system which intensifies all the evils of the pail system, and is without any of its advantages. In rural districts, where there is no public water supply, it may still linger; but the difficulty of getting privies regularly emptied increases every year. The introduction of preserved articles of diet has led to empty tins, broken bottles, etc., being thrown into the ash-pits, and I have heard farmers declare that it has cost them as much to sort the contents of privy-middens, or to pick up the old tin cans, from their fields, as they have been paid for removing the refuse.

Where sewers have been provided, why not make full use of them? The only system fitted for this country is that of water-closets. The water comes silently into the houses, and does its work efficiently; the excreta are removed at once before the mass has time to give rise to any nuisance by decomposing. The danger of sewer gas entering a house is just as great from a bath or sink as from a water-closet if the house drains are not disconnected from the public sewer, while there is no more difficulty in disconnecting a water-closet than there is in cutting off a bath waste. Both should be trapped, and then made to pass *through the open air,* in a disconnecting trap (see Fig. 1), before passing into the sewer. If this simple precaution is taken, and the drains are not defective, it is impossible for sewer gas to enter the house; while the risk of the drains being defective is not increased by the fact that there is a water-closet within the house.

Although this matter does not arise on the question of sewage disposal, it is of such importance that I feel I am justified in introducing a sketch showing the proper method of disconnecting water-closets, bath and sink wastes, from the sewers. This is done in Fig. 1.

That danger of typhoid fever from the adoption of the water-carriage system, if properly carried out, does not exist, is clearly demonstrated in the case of London. Here is the largest population ever congregated together, water-closets generally adopted, and a low typhoid rate. That water-carriage is the healthiest system has been conclusively shown by Dr. Boobyer in the case of Nottingham, the following

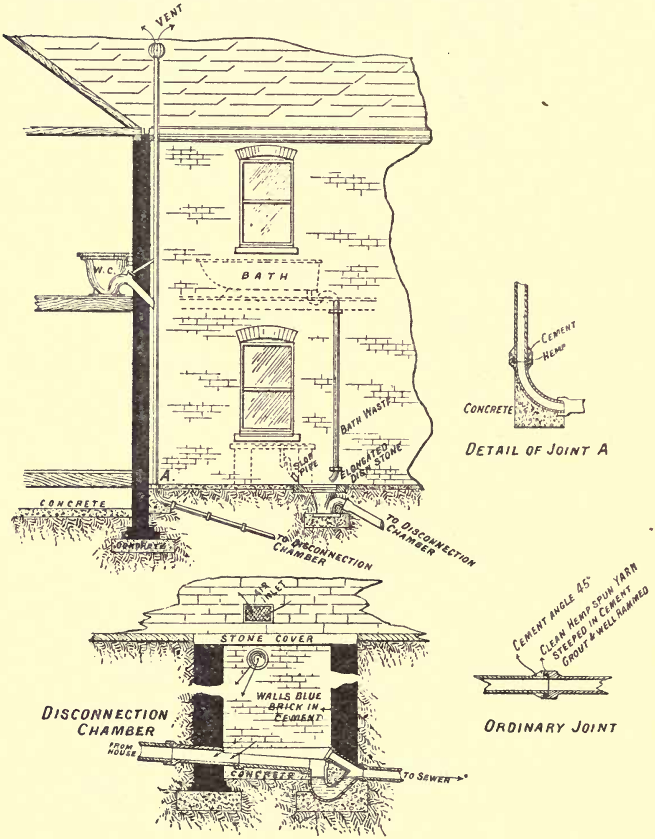

FIG. 1.—METHOD OF DISCONNECTING HOUSE DRAINS FROM PUBLIC SEWERS.

summary giving the incidence during the last ten years of typhoid fever on houses with water-closets, pails, and privy-middens:—

Privy-midden	houses,	1	case of	typhoid in	37
Pail-closet	„	1	„	„	120
Water-closet	„	1	„	„	558

In the face of these figures, the advantage of the water-carriage system is apparent.

CHAPTER II.

THE CHEMISTRY OF SEWAGE.

Variations of sewage with water supply—Composition of average sewage—Explanation of chemical terms used—Total solids, free ammonia, organic or albuminoid ammonia, chlorine, oxygen absorbed—Formula for calculating flow—Standards of purity for sewage effluents—Chemical changes to be effected by purification.

An average sewage contains about 100 grains of solid matter to the gallon, the remaining 69,900 grains being water. Of the 100 grains of solid matter, a certain proportion, varying in different towns and at different times of the day and seasons of the year, will consist of organic matter; perhaps on the average it will amount to 40 grains. It is the object of sewage purification to remove, as far as possible, this 40 grains of organic matter, and to as nearly as possible completely oxidize that which cannot be removed. All the organic and mineral matter in suspension should be removed, and in a good effluent as much as 80 per cent. of the organic matter in solution will also be oxidized to nitrates. An average sewage, containing 100 grains of solid matter to the gallon, will have about 70 grains in solution; this includes the solid matter in solution in the drinking water of the district. Consideration of this fact will at once show that the solid matter in solution in a sewage must vary in different towns with the quality of the drinking water. A glance at the following Table, giving the solid matter in water supplies from various sources, will show how the percentage of solid matter in a sewage varies with the source of the public water supply :—

GRAINS OF SOLID MATTER TO THE GALLON IN VARIOUS WATERS.

Formation.	Surface waters.	Deep well and spring waters.
Igneous rocks, Metamorphic, Silurian, and Devonian	3 to 7	5 to 15
Yoredale and Millstone Grits	5 to 10	15 to 28
New Red Sandstone	8 to 18	20 to 30
Mountain Limestone	8 to 16	22·5
Magnesian Limestone	8 to 18	35·0
Chalk	—	25·0
Chalk beneath London Clay	—	54·5
Coal Measures	16	60·0

It will be seen that the percentage of solid matter in solution in the sewage from a town supplied with water from a deep well in the coal measures, for instance, will be ten times greater than that from a town which is supplied with surface water from a gritstone gathering ground. It is obvious that, as far as the purification of sewage is concerned, the amount of this solid mineral matter in solution is of secondary importance. An average sample of sewage, containing 100 grains of solid matter to the gallon, will have about 70 grains of solid matter in solution and 30 in suspension. Of the suspended matter a varying amount, somewhere about two-thirds, will be organic matter, while of the other in solution less than one-third will be organic matter.

The following Table may be useful as giving an idea of the solid matter in an average sewage:—

COMPOSITION OF ONE GALLON OF TYPICAL AVERAGE SEWAGE.

	Grains per gallon.	
(1) Solid matters in suspension—		
(*a*) Organic	20	
(*b*) Mineral	10	
		30
(2) Solid matters in solution—		
(*a*) Organic	20	
(*b*) Mineral	50	
		70
Total		100

A gallon of water weighs 70,000 grains, so that 70 grains per gallon is equivalent to 100 parts in the 100,000. As the decimal notation is used in chemical investigations, it is easier to express results in parts per 100,000 than in grains per gallon. In this work results will be expressed in parts per

100,000. It is a simple matter to convert grains per gallon to parts per 100,000 by dividing by 7 and multiplying by 10; similarly parts per 100,000 can be converted to grains per gallon by multiplying by 7 and dividing by 10.

Such a sewage as the above would, upon analysis, probably yield results somewhat as follows, expressed in round numbers in parts per 100,000 :—

Total solids.	Solids in suspension.	Chlorine.	Free ammonia.	Organic ammonia.
142·8	42·8	12·0	5·0	1·0

Nearly all the solid matter in suspension and a fraction of that in solution can be removed by almost any precipitating process, such processes about half purifying the sewage. In the laboratory the solid matter in suspension is removed by passing the sewage through filter paper. The quantity can be thus estimated. After the removal of the suspended matter, there is still the 20 grains of organic matter in solution to purify. As we shall see, this organic matter in solution, having as its chief source the urine which enters the sewers, contains the bulk of the nitrogen in the sewage and cannot be removed. Its purification can only be effected by completely oxidizing it, so that when it enters a river its affinity for oxygen is satisfied and it does not deprive the river of its normal oxygen which is required for the natural fauna and flora of the river water.

The chemical terms which are used in relation to sewage are various, but the following are the only terms we need trouble with, as they indicate the only determinations which it is necessary should be made.

Total Solids.—The meaning of the term "solid matter" has been fully explained. It is determined by evaporating to dryness in a platinum dish a known quantity of sewage over a water bath, drying at 212° Fahr., and weighing immediately on cooling. The result obtained is the total solid matter. The total organic matter is then determined by igniting the residue in the platinum dish and weighing again; the loss on the first weighing gives the total amount of organic matter which has been burnt off. The sewage is then filtered, and the same process is gone through again with the filtered sewage; the results obtained will give the total solids and the organic solids in solution. By subtracting these from the first results the total suspended matter and the organic suspended matter will be obtained. A good sewage effluent should contain no organic matter in suspension, and not more than three parts per 100,000 of organic matter in solution.

Free Ammonia.—This is the ammonia formed from the splitting up of the nitrogenous matters in the sewage by the action of bacteria. There are at least two varieties of bacteria which split up the urea in the urine and convert it into carbonate of ammonia. Although the term "free ammonia" is used, the ammonia is not to be understood to exist in the free state, using the word "free" in its chemical sense. It is in combination with carbonic and organic acids, and if mineral acids enter the sewers it may also exist as the chloride or the sulphate of ammonium. The term "bacteriolysis" has been proposed for this splitting up of organic matter by the action of living organisms. The free ammonia in itself is quite harmless and is not of much importance.

The Organic or Albuminoid Ammonia and the Organic Nitrogen.—The organic matter of animal origin both in solution and in suspension contains about sixteen per cent. of nitrogen; the vegetable organic matter contains much less. At one time the organic nitrogen was estimated as an index of the amount of organic matter. The process, however, has not been generally adopted.

Wanklyn showed that by boiling organic matter with permanganate of potash and caustic potash it was split up, and a proportion of the nitrogen was given off in the form of ammonia, which could easily be estimated, and was as reliable as an index of the organic matter as the organic nitrogen proposed by the old Rivers Pollution Commissioners. The terms "albuminoid" and "organic ammonia" are synonymous. As a rule, about two-sevenths of the organic nitrogen in sewage will come off as organic ammonia. This is perhaps the most important determination that can be made of sewage and sewage effluents. The organic ammonia in a sewage varies from 3 or even more parts per 100,000, to as little as 0·2 part per 100,000, while that in a sewage effluent should not yield more than 0·1 part per 100,000. The Table on page 29 gives the results of the average of a number of samples of sewage from different sources. It will be seen that the American sewage is very much weaker than average English sewage.

Chlorine.—The chlorine in sewage has its origin in common salt, of which it constitutes about 60 per cent. It enters the sewage as salt in the waste from kitchens and in the urine. There is also a certain amount of chlorine in all drinking water. It is also present, to a slight extent, in rain water. On the West Coast as much as 5 parts per 100,000 have been found in rain water; at Liverpool 1 part; and in various parts of England (inland) about 0·3 per 100,000. The chlorine in drinking waters varies with the source of the water; in upland surface waters it is about 1 part in 100,000, while in the deep-well waters from the millstone grit, new red sandstone, mountain limestone, chalk, Devonian rocks, it is about 2 or 3 parts; while in the chalk beneath the London clay it is as much as 15, and in the coal measures even 18 parts per 100,000. So that the amount of chlorine in sewage will very materially depend upon the drinking water supplied to the district.

Human urine, of which on the average, in a mixed population, about 40 ounces per head per day are excreted, contains about 842 parts per 100,000 of common salt, of which 500 parts consist of chlorine. The chlorine itself is of little importance; there is no necessity for its removal, and *no process of purification can remove it.* Its determination, however, is important, because it serves as a valuable index of the strength of ordinary domestic sewage. For instance, one frequently sees in the advertisements of patented processes of purification, an analysis published of the wonderful purity of a sewage effluent which contains a small amount of chlorine, and beside it an analysis of the raw sewage which contains a much larger amount of chlorine. Obviously the effluent and sewage do not correspond, and the effluent has been obtained from a weaker raw sewage than that of which the analysis is published.*

From this it will be obvious that the determination of chlorine is always an important one, as, if the percentage of purification effected by any process is to be gauged, the chlorine in the effluent must be practically the same as that in the sewage. It is a

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* In a paper read at the Sanitary Institute Congress, Liverpool, in 1894, on a "patented" process of purification, the chlorine in a raw sewage was given as 30 parts per 100,000; while that in the effluent from the "patent" filters was given as 3·9 parts per 100,000. The effluent must have been from a sewage of between one-seventh and one-eighth of the strength of that purporting to be the sewage before purification.

pity that this elementary fact has not been more generally appreciated by the advocates of many patented processes, as the analyses they publish prove too much.

The chlorine in twenty samples of sewage from midden towns was found by the Rivers Pollution Commissioners to contain 11·54 parts per 100,000; while that from 36 water-closet towns contained 10·66 parts. The drainage from districts where the wash water after dyeing enters the public sewers contains less chlorine than average sewage; while the drainage from 15 districts where bleaching, fulling, and scouring were carried on was shown by the Rivers Pollution Commissioners to contain 20 parts per 100,000; the drainage from paper mills contained about the same. The drainage from alkali works contained from 100 to 700 parts; while that from galvanizing and tin-plate works on the average contains 2000 parts, and may contain as much as 20,000 parts per 100,000. From this it will be seen that the amount of chlorine in the sewage will depend upon the nature of the manufacturing refuse.

If the sewage is purely of a domestic nature, and there is a public water supply, the amount of chlorine in it being known, the strength of the sewage and the number of gallons per head can be approximately ascertained by estimating the quantity of chlorine in the sewage. The following is a formula which the author has devised for this purpose, and which gives approximately accurate results:—

Let A = parts per 100,000 of chlorine in the public water supply, and let B = the parts per 100,000 of chlorine in the sewage; let X be the number of gallons of sewage per head per day required to be ascertained—

$$X = \frac{125}{B - A}$$

For example, on a recent occasion the chlorine in the Buxton drinking water was found to be 1·1 parts per 100,000 (A) = 1·1, and the chlorine in the sewage to be 2·3 (B) = 2·3:

$$X = \frac{125}{2{\cdot}3 - 1{\cdot}1}$$

= 104 gallons per head per day. As a matter of fact, the flow was actually about 100 gallons per head per day.

The Oxygen absorbed in Four Hours at Eighty Degrees Fahrenheit.—On adding a solution of permanganate of potash to a sewage, the permanganate becomes decolourized on account of its giving off a portion of its oxygen to the organic matter. Unfortunately, besides organic matter, salts of iron and other substances decolourize permanganate, so that however suitable the process is for the purpose of water analysis—for which Dr. Tidy originally introduced it—more reliance is to be placed upon the albuminoid ammonia as an index of the amount of organic matter present in sewage, particularly where iron salts are used as a precipitant. Speaking generally, the oxygen absorbed in four hours at 80° Fahr. is about ten times the amount of albuminoid ammonia.

The Mersey and Irwell Joint Board have adopted this process as a rough standard of purity for sewage effluents.

Taken in conjunction with the albuminoid ammonia process, reliable results can be obtained.

Standards of Purity for Sewage for Effluents.—No standard of purity for sewage effluents is fixed by the Rivers Pollution Prevention Acts, but from time to time various bodies have made suggestions as to what in their opinion should be adopted as a standard.

It will be admitted at once that any standard to be generally applicable, while being sufficiently high to prevent any nuisance arising from the contamination of a stream with an effluent which complies with it, should be sufficiently low to enable any Authority to keep within its limits. The Commissioners appointed in 1868 to inquire into the best means of preventing pollution of rivers recommended that it should be inadmissible to admit into any stream a liquid with the following composition :—

	Parts of 100,000.
Total suspended matter	4·0
Organic ,, ...	1·0
Organic carbon	2·0
Organic nitrogen	0·3

They then went on to give other conditions which apply only to the effluents from manufacturing processes. It is sufficient to say here that, in addition to the above, a sewage effluent should neither contain free alkali nor free acid.

The Local Government Board have more than once been asked to specify a standard of purity for sewage effluents, but they have refused, on the ground that all the circumstances of each case should be taken into consideration. In the practical working of the Rivers Pollution Prevention Act it is absolutely necessary that those who have to enforce the Act should have some standard before them. The Mersey and Irwell Joint Board have adopted 1·4 parts per 100,000 (one grain per gallon) of oxygen, absorbed at 80° Fahr. in four hours, as the standard for passable effluents; effluents absorbing less than 1 part being classed as good, less than 1·4 as fair, up to 3 as unsatisfactory, and more than 3 as bad. It is worth noting that in a recent report to the Board by their chief inspector it is shown that considerably over half the samples examined were within the limits of passable effluents. The standard which the Derbyshire County Council have adopted is 0·1 part per 100,000 of albuminoid ammonia. With regard to this standard, it can easily be reached by any of the recognized methods of treatment. The usual objection to the adoption of a general standard is that sanitary authorities would be tempted to dilute their effluent with subsoil or other water until the standard was reached. This would be prevented by insisting upon the effluent having undergone sufficient nitrification to contain at least 0·25 part of nitrogen as nitrates in the 100,000.

The following standard, taking four factors into consideration, would, in the author's opinion, be generally suitable :—

		Parts per 100,000.
Total suspended matter	less than	3·0
Oxygen absorbed at 80° Fahr. in 4 hours	,, ,,	1·5
Albuminoid ammonia	,, ,,	0·15
Nitrogen as nitrates to be at least ...	... ...	0·25

The Changes to be effected by Purification.—The typical average sewage which we have previously considered had the following composition expressed in parts per 100,000 :—

Total solids	142·0
Solids in suspension	42·0
Chlorine	12·0
Free ammonia	5·0
Organic ammonia	1·0

Such a sewage by precipitation would have the solid matter in suspension removed, and in this process the organic ammonia, "the index of the organic matter," would be reduced from 1 to perhaps 0·40. The same result would happen if the sewage was passed over the surface of land which intercepted the solid matter in suspension; the purification which would so far be carried out would be merely clarification or removal of suspended matter. The sewage would still have the organic matter in solution in it, and whether it is intermittently passed through the open soil, such as sand or gravel, or whether it has passed through artificially prepared filters of polarite, crushed coal, coke-breeze, coarse sand, or any other suitable substance, the change which takes place is the same.

It is essential that the sewage should be applied *intermittently* to the land or filters, so that the air in the interstices of the filtering medium may by this means be periodically renewed. Unless this takes place the nitrifying organisms cannot oxidize the ammoniacal salts and convert them first of all into nitrous acid, and finally into nitric acid, from two-thirds to three-fourths of which acids are oxygen. When these acids are formed they immediately replace the carbonic acid in the carbonates of lime, potash, or whatever base the carbonic acid present is combined with, and form nitrates of such bases. The nitrogen in solution therefore passes away in the sewage effluent as a nitrate; it is not removed. These nitrates are quite harmless; as a rule nitrate of lime is the particular nitrate which is formed. The general characteristics of nitrates are similar to nitrate of potash or saltpetre.

If such a sewage as the average one previously referred to were strained through filter-paper, the organic ammonia would be reduced from 1·0 to about 0·50 part per 100,000. All the matters in suspension would be removed, two-thirds of which we have seen are organic matter, being half the total organic matter in the sewage. In the laboratory, also, by carefully regulated experiments with precipitants, the whole of the suspended matters can be thrown down, and from 10 to 25 per cent. of the organic matter in solution; the organic ammonia, upon analysis, being reduced to 0·40, or slightly less. But in practice, by precipitation, the solid matters in suspension, and not more than 10 per cent. of the organic matter in solution, are removed.

The removal of the suspended matter is the easiest part of the process of sewage purification. The change is a physical one, whether the suspended matters are arrested mechanically on the surface of the soil, as in irrigation, or are entangled by a chemical during precipitation, and carried to the bottom of a precipitation tank. The rest of the purification is a biological action, the organic matter in solution not being removed, but oxidized by the nitrifying bacteria.

The results of the analysis of the average sewage, after going through these two changes, are exemplified in the following Table :—

	Parts per 100,000.				Nitrogen as Nitrites and Nitrates.
	Total Solids.	Chlorine.	Free Ammonia.	Organic Ammonia.	
Raw sewage	142	12·0	5·0	1·0	Nil.
After precipitation	105	12·0	4·5	0·45	Nil.
Ditto and filtration	100	12·0	0·5	0·08	1·5

It will be noticed that by the precipitation the suspended matter has been removed, and that the solid matter in solution has practically only been diminished by the removal of the solid matter in suspension, while the chlorine has not diminished at all. An effluent, such as that above, if bottled up and kept in the dark at a warm temperature may become foul, but when diluted with running water and exposed to the air and light will not become a nuisance. The author has within his knowledge a case where a river, after receiving the effluent from sewage works, passed down crevices in the bed of the stream into a cavity in the limestone, where it stagnated without the access of air and light, and periodically overflowed into the river. At the times when this matter overflowed a considerable nuisance from sulphuretted hydrogen was occasioned. The organic ammonia in the mixed sewage effluent and river water upon analysis was found to be 0·10 part per 100,000; the effluent itself varied from 0·12 to 0·25 part per 100,000, and contained no nitrates.

Bottles of this mixture of river water and sewage effluent, in which mixture the organic ammonia was 0·11 part per 100,000, were hermetically sealed and placed in the dark for several weeks, when they gave off the smell of rotten eggs. The whole of the oxygen in solution in the water was taken up by the sewage matter. The above experiment is sufficient to show that the standard suggested of 0·1 per 100,000 of albuminoid ammonia is not unnecessarily stringent; the author suggested it to his Authority as a provisional standard until all the sanitary authorities in his county have levelled up to it. He is fully aware that many authorities turn out effluents with albuminoid ammonia less than 0·05 or even 0·04 per 100,000; but, in the first instance, it is advisable to fix such a standard that all Authorities without exception can comply with it.

The Rivers Pollution Commissioners, in their sixth report, gave a large number of analyses of effluents from sewage farms; the organic ammonia is not given, but the organic nitrogen is given as 0·191. If we take the organic ammonia which will be yielded as two-sevenths of this, 0·054 would be the organic ammonia in the effluents tabulated by them. It will be remembered that the organic nitrogen which they suggested should be taken as a standard in 1868 was 0·3; again, taking two-sevenths of this as the organic ammonia, we have a standard of 0·086, a more severe standard than the one suggested. The London County Council experiments on various methods of filtering sewage also showed that a standard of 0·1 per 100,000 could easily be complied with. The average result of 14 experiments on filtering through coke breeze was 0·1 per 100,000; and after filtering through polarite, 0·088 per 100,000.

The Sewage Committee of the British Association reported in 1870 that the effluent water from the sewage farm at Romford contained 0·037, 0·035, and 0·036 parts of albuminoid ammonia per 100,000. The following year (1871) they reported the effluent contained 0·064 and 0·045, while the effluent from Norwood farm contained 0·06, and the Tunbridge Wells farm 0·09; the effluent water from Reigate farm contained 0·06 part per 100,000 of albuminoid or organic ammonia; and the effluent from the Berley sewage farm contained from 0·039 to 0·05 parts per 100,000. It will, I think, therefore be conceded that a standard of 0·15 part per 100,000 of albuminoid ammonia, and 1·5 of oxygen absorbed at 80° Fahr. in four hours, is one that all Authorities should be called upon to comply with, the danger of diluting down to this standard being prevented by also insisting upon the effluent containing at least 0·25 part per 100,000 of nitrogen in the form of nitrates.

CHAPTER III.

VARIETIES OF SEWAGE AND THE CHANGES IT UNDERGOES.

Chemical composition of different sewages—Variations in the Chlorine—Night and day sewage—Hourly variations in flow and composition—Changes sewage undergoes by keeping—Purification effected by clarification, nitrification and bacteriolysis—Importance of sewers being self-cleansing—Table giving maximum discharge of various sized sewers at different inclinations.

The following Table gives the average composition of a number of sewages. It will be seen that American sewage is much weaker than English, this of course being due to the larger amount of water used. Buxton also has an exceptionally weak sewage, the water from the celebrated public springs being passed into the sewers. It should be pointed out that Buxton is a water-closet town. A comparison of this sewage or that of London and of the 36 water-closet towns, with that from the 20 midden towns, clearly shows that the sewage from a water-closet town is no stronger than that from a midden town.

AVERAGE COMPOSITION OF SEWAGE. PARTS PER 100,000.

Source of Sewage.	Total solids.	Solids in suspension.			Chlorine.	Ammonia.		Authority.
						Free.	Organic.	
American Sewage.								
(1) Laurence, Massachusetts ...	43·0	8·2	...		4·8	1·2	0·40	Reports of State Board of Health, Massachusetts.
(2) Worcester, Massachusetts ...	43·4	9·9	organic mineral	4·7 5·2	4·3	0·55	0·178	Ditto.
English Sewage.								
(3) Buxton	45·0	5·5	organic mineral	3·8 1·7	2·3	1·05	0·291	Author.
(4) Exeter	54·4	24·5	organic mineral	14·5 10·0	5·0	3·7	0·212	W. J. Dibdin.
(5) London	123·5	39·6	organic mineral	21·4 18·2	15·2	4·6	0·55	W. J. Dibdin.
(6) 20 midden towns	119·5	39·1	organic mineral	21·3 17·8	11·5	5·4	0·56*	First Report of River Pollution Commissioners.
(7) 36 water-closet towns ...	116·9	44·7	organic mineral	20·5 24·1	10·6	6·7	0·63*	Ditto.
(8) Salford	150·0	28·4	organic mineral	16·4 12·0	41·0	1·84	0·68	Average of analysis by Dr. Burghead and Mr. Carter Bell.
(9) Chesterfield	130·0	54·0	organic mineral	30·0 24·0	11·5	3·3	1·8	Author.
(10) Derby	137·0	57·0	organic mineral	30·0 27·0	9·9	7·2	1·12	Author.
(11) Alfreton (few water-closets)	204·0	80·5	organic mineral	48·0 32·5	17·4	8·3	1·64	Author.
(12) Sewage from slop-closet village, Stafford	158·0	...	...		19·6	19·7	2·58	Dr. George Reid.
(13) Wolverhampton (not an average sample)	496·0	50·0	...		173·0	1·72	1·17	C. W. T. Jones, F.I.C.
(14) Burton-on-Trent	224 {110 114	65·0	organic mineral	45·0 20·0	12·0	1·6	2·0	Author.
Ditto, after straining ...	...	...	...		...	1·6	0·88	
Ditto, after precipitation with lime and exposure to the air	...	...	...		...	1·8	0·68	
(15) Berlin	218·3	113·8	organic mineral	75·5 38·3	21·8	12·8		Report on Berlin Sewage Farm.

* Estimated by taking $\frac{2}{7}$ of the organic nitrogen.

The chlorine, it will be seen, varies from 2 to 173 parts per 100,000. In the strongest domestic sewage, when the water supply is only 5 or 6 gallons per head, the chlorine will be about 15 parts per 100,000 over that in the drinking water. The strongest domestic sewage the author is aware of is that given in sample No. 12, and the chlorine was 19·6. It was from a group of new houses, all of which were provided with slop water-closets, the excreta being removed by the slop water accumulating in tipplers which automatically flushed the closets.

In the case of the Berlin sewage the chlorine is 21·8. This high amount of chlorine is accounted for by the fact that from the baths in the Admiral's Gardens 2,000,000 kilograms of salt pass yearly into the sewers. At Salford the high chlorine is accounted for by the bleach, dye, and other manufacturers' wastes which enter the sewers; and the extremely high figure in the Wolverhampton sewage is caused, of course, by the galvanizers' pickle. The albuminoid or organic ammonia is on the whole the most important result of analysis to look at, as it is an index of the polluting organic matters. It varies from about 0·25 in weak sewage to 3, or occasionally more, parts per 100,000.

It has been pointed out that the composition of sewage varies at different times of the day. Thus the Sewage Committee of the British Association, in their Report for 1870, give the following analyses of Bury sewage:—

	Parts per 100,000.	
	Collected during day.	Collected during night.
Total solids	137	38·6
Solids in suspension ...	64·8	Trace
Chlorine	13·6	4·7
Ammonia	3·8	0·76
Organic ammonia	0·198	0 04

This variation in the composition of sewage is a matter that must be carefully borne in mind, as it has frequently been taken advantage of by interested persons to show an undue percentage of purification. If it takes five hours for the sewage to pass through the purification works, and a sample of the effluent and the raw sewage are taken at the same time, say about ten a.m., it will be evident that the effluent is from the night sewage; and in the case of Bury, though no purification at all were taking place, it might be claimed that the organic matter as indicated by the organic ammonia was being reduced nearly 80 per cent. The determination of the chlorine in the sewage would, however, show that the sewage and the effluent were not comparable. One reason for the night sewage becoming so weak is that water-taps are left running, as well as the dilution of the sewage with the subsoil water. This leakage of the subsoil water into the sewers took place to a much greater extent with the old brick sewers than it does with sanitary pipe sewers laid with cement joints.

In 1870 Mr. Bailey Denton reported to the Sewage Committee of the British Association that at Blackpool the sewage was actually 1,000,000 gallons a day, when the amount calculated from the water supply was 250,000 gallons, while at Hartford the discharge from the sewers was nine times the water supply. On a sewage farm recently constructed in the author's district, before a single house was coupled with the sewers, 40,000 gallons a day of water were delivered at the farm.

The following hourly estimations, by Mr. F. Perkins, F.I.C., of the chlorine in the Exeter sewage, show, when taken in conjunction with the hourly gaugings of the sewage, that its strength gradually increases in the daytime *pari passu* with the volume of the sewage :—

	Parts per 100,000. Chlorine.
6·20 a.m.	2·2
7·20 ,,	2·6
8·20 ,,	3·2
9·20 ,,	4·4
10·20 ,,	9·2
11·20 ,,	10·8
12·20 p.m.	10·2
1·20 ,,	8·0
2·20 ,,	8·7
3·20 ,,	6·0
4·20 ,,	14·25
5·20 ,,	7·0
6·20 ,,	7·0
7·20 ,,	5·2
8·20 ,,	5·0
9·20 ,,	6·0
10·20 ,,	4·4

	Parts per 100,000. Chlorine.
11·20 p.m.	4·6
12·20 a.m.	4·0
1·20 "	3·4
2·20 "	2·8
3·20 "	2·6
4·20 "	2·6
5·20 "	2·3

N.B.—The chlorine in the drinking water is 1·3, but that in the subsoil water will probably be higher.

In every case the sewage becomes weaker in the small hours of the morning, and where the sewers have tapped much ground water it becomes for an hour or two, about 4 a.m., quite clear and almost innocuous.

The diagrams in Fig. 2 (next page), after Santo Crimp, show the variation in the hourly flow of the sewage at a number of towns, and they should be compared with the estimations of the chlorine in the Exeter sewage.

As a rule, half the sewage passes off in eight hours, viz. 9 a.m. to 5 p.m. As there is always some leakage of subsoil water and some dilution from water-taps left running, it will be obvious that the sewage will be most diluted when the flow is least, and strongest when the flow is greatest. The fresher the sewage the less the organic matter in solution, and the more the sewage is agitated by pumping, etc., the more the solid matter is broken up and the more it enters into solution.

In addition to the variations due to the *amount* of water, a considerable difference in the nature of

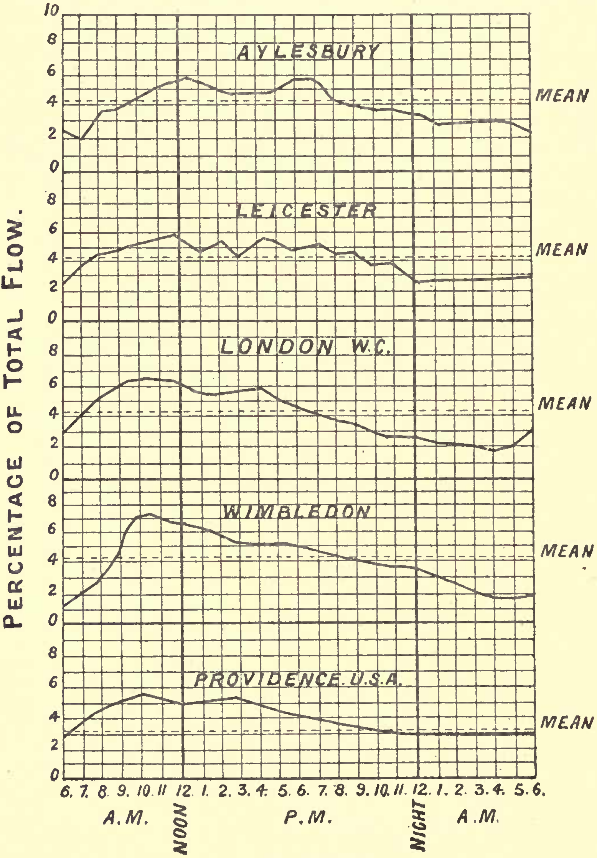

FIG. 2.—Diagram showing HOURLY FLOW OF SEWAGE (reproduced, by permission, from W. Santo Crimp's "Sewage Disposal Works," published by C. Griffin & Co., Limited, London).

sewage is caused by the quality of the water in use in the district, and this is a point which has some influence on the question of treatment. From the point of view of the sewages they produce, waters may be grouped into three classes: soft waters, such as upland surface waters; waters with a moderate temporary hardness; and waters of a high permanent hardness containing sulphates.

The sewage from a town with a soft water will probably have to have lime added to it in the process of treatment to act as a base to the nitric acid which, we shall see, it is the object of sewage purification to form; while sewages formed from waters of the last group are liable to undergo decomposition with the production of sulphuretted hydrogen from the reduction of the sulphates; so that on the whole a water with a moderate temporary hardness from carbonate of lime in it forms the easiest sewage to treat.

From what has been said, it will be seen that sewage is an extremely complex and unstable liquid. When quite fresh it is practically inodorous, and, if not coloured by manufacturing wastes, is opalescent and of a light grey colour. Allowed to stand in a glass, a varying amount of solid matter will be seen to settle to the bottom, while particles of suspended matter, such as filaments from paper and fabrics, albuminous flocculi of animal tissues, and shreds of vegetable matter, will be found floating in it; and upon the surface particles of a fatty and soapy nature will accumulate.

The great bulk of the nitrogen in the sewage leaves the human body in the urine in the form of urea. Chemically, urea, which is the last product of the oxidation of albuminous foods, is of the following composition, $CO\left\{\begin{matrix}NH_2\\NH_2\end{matrix}\right.$, and when obtained pure and dry assumes the form of colourless glistening crystals, without smell, and of a cooling and nitre-like taste. But almost immediately upon leaving the body it is attacked by one or other of two micro-organisms constantly present in the air, the *bacillus ureæ* and the *micrococcus ureæ* of Pasteur. Both of these organisms rapidly convert urea into carbonate of ammonia. The change which takes place may be expressed chemically as follows :—

$$\begin{array}{ccccc} \text{UREA} & + & \text{WATER.} & & \text{Carbonate of Ammonia.} \\ CO\left\{\begin{matrix}NH_2\\NH_2\end{matrix}\right. & & OH_2 & = & (NH_4)_2\ CO_3 \end{array}$$

This is the substance which gives stale urine and stables their pungent smell.

By the time the sewage reaches the sewage disposal works, as a rule the urea is completely transformed. If the sewage is kept without undergoing purification for a day or so it undergoes putrefaction, and begins to give off foul emanations; in the course of two or three days the albuminous matters begin to split up, and the sewage, particularly when the water contains sulphates, yields sulphuretted hydrogen, which is known by its characteristic odour of rotten eggs. When this gas is formed the sewage becomes black. As the above changes take place, more and more of the solid matter enters into solution, and the sewage becomes proportionately more difficult to treat, at any rate by a precipitation process.

The changes which take place may be expressed by the following empirical formula:—

2 parts of albumen,* consisting of— take up 18 parts of water, consisting of—

$$2\left\{\begin{array}{l}7 \text{ atoms of carbon}\\ 1 \text{ ,, ,, hydrogen}\\ 2 \text{ ,, ,, nitrogen}\\ 3 \text{ ,, ,, oxygen}\end{array}\right. + 18\left\{\begin{array}{l}2 \text{ atoms of hydrogen}\\ 1 \text{ ,, ,, oxygen}\end{array}\right.$$

and thus form

2 parts of carbonate of ammonia, consisting of— 2 parts of marsh gas, consisting of— 8 parts of carbonic acid, consisting of— 7 parts of hydrogen

$$2\left\{\begin{array}{l}1 \text{ atom of carbon}\\ 8 \text{ atoms of hydrogen}\\ 2 \text{ ,, ,, nitrogen}\\ 3 \text{ ,, ,, oxygen}\end{array}\right. \quad 2\left\{\begin{array}{l}1 \text{ atom of carbon}\\ 4 \text{ atoms of hydrogen}\end{array}\right. \quad 8\left\{\begin{array}{l}1 \text{ atom of carbon}\\ 2 \text{ atoms of oxygen}\end{array}\right. \quad \begin{array}{c}\text{consisting of}\\ \text{14 atoms of}\\ \text{hydrogen}\end{array}$$

and 2 parts of carbon monoxide, consisting of 2 atoms of carbon and 2 atoms of oxygen;

or briefly thus:—

$$2C_7HN_2O_3 + 18H_2O = 2(NH_4)_2CO_3 + 2CH_4 + 8CO_2 + 7H_2 + 2CO$$

From what has been said, I think it will be seen

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* The percentage composition of albumen is approximately 52 parts carbon, 7 parts hydrogen, 22 parts oxygen, 16 nitrogen, and 1 sulphur.

that there can be no one process equally suitable for every sewage, but that the method of treatment for any particular sewage must depend upon the nature of the sewage, its freshness at the outfall, the character of the manufactures, and the quantity and quality of the water supply of the district. There are, however, certain general principles which are the same in every process of sewage purification, from irrigation on a sewage farm to the latest artificial schemes of purification by precipitation and filtration through specially constructed filters.

Instead of describing the various processes which are now in use according to the name of the process or the name of the inventor of the process, I propose to deal with the subject under three chief headings: (1) The defœcation or clarification of the sewage, by which I mean the removal of the solid matters in suspension, this generally being effected by precipitation; (2) The nitrification of sewage, by which is meant the conversion of the polluting nitrogenous matter in solution into nitrates; and (3) The bacterial process, or the new departure, including the Exeter septic process, in which the solid matters are split up by anaerobic germs which work in the absence of air, and the other processes in which aerobic organisms are utilized.

As the solid matter in suspension in the sewage can be entirely removed, while that in solution cannot be removed, but must be oxidized to render it harmless, it follows that the sewers should have a good gradient so as to bring the sewage as rapidly as possible to the outfall works. Where much manufacturing waste containing organic matter and hot water is poured into the sewers, there is still greater need for the sewage to be brought quickly to the outfall works. This is more especially the case with brewery waste, which contains much unstable organic matter, degenerate yeast, a lot of water used in the cooling, and, as a rule, a water supply containing sulphates.

When such conditions as the above are present, it is most important that there should be no chance of even a temporary deposit in the sewers, and every means should be taken to cause the sewage to flow as rapidly as possible, as unless this is done the organic matter will be split up, the sulphates reduced, and large volumes of sulphuretted hydrogen be evolved, which gas will enter into chemical combination with the iron salts or lime used as a precipitant, and thus render them to that extent inert, so that large quantities of the precipitant have to be used.

The following observations on "bottom velocities" were made by the late Mr. Beardmore:—

30 feet a minute will not move clay with sand and stones.
40 ,, ,, will move coarse sand.
60 ,, ,, ,, ,, pea gravel.
120 ,, ,, ,, ,, 1 in. rounded pebbles.
180 ,, ,, ,, ,, 1¾ in. angular stones.

The bottom is between three and four-fifths of the surface velocity, and it should always be sufficient to render the sewer self-cleansing. Under no condition should the velocity be less than two feet per second.

The following Table gives the maximum discharge per minute of various sized sewers within the range of permissible fall. A glance at it is sufficient to show that, if a sewer had only to convey the sewage undiluted with rain water, much smaller sewers than are generally used would be sufficient, but there is also a certain amount of rainfall which must be allowed to enter the sewers; this is usually calculated at $\frac{1}{4}$ of an inch per diem upon the inhabited area. After the normal dry weather sewage is diluted 8 times with rain water. It should be arranged for storm overflows discharging upon the surface of rough open filters to come into action.

TABLE GIVING THE MAXIMUM DISCHARGE* IN GALLONS PER MINUTE OF VARIOUS SIZED PIPES AT DIFFERENT INCLINATIONS WITHIN PERMISSIBLE LIMITS.

RATE OF INCLINATION.	4″ PIPES.	6″ PIPES.	9″ PIPES.	12″ PIPES.	15″ PIPES.	18″ PIPES.	24″ PIPES.
	Discharge in gallons per min.	Discharge in gallons per min.	Discharge in gallons per min.	Discharge in gallons per min.	Discharge in gallons per min.	Discharge in gallons per min.	Discharge in gallons per min.
1 in 5 ...	410	1096	2902	5746	9728	14900	29059
1 ,, 6 ...	378	1016	2700	5369	9117	14009	27433
1 ,, 7 ...	352	951	2538	5061	8612	13267	26080
1 ,, 8 ...	332	898	2400	4801	8188	12632	24909
1 ,, 9 ...	314	851	2287	4581	7821	12077	23887
1 ,, 10 ...	299	812	2186	4385	7503	11603	22989
1 ,, 15 ...	246	674	1828	3695	6356	9865	19718
1 ,, 20 ...	210	588	1602	3250	5582	8743	17543
1 ,, 25 ...	191	528	1441	2936	5077	7927	15978
1 ,, 30 ...	174	483	1324	2697	4672	7310	14782
1 ,, 35 ...	161	446	1227	2510	4351	6817	13803
1 ,, 40 ...	151	418	1151	2354	4090	6406	12999
1 ,, 45 ...	141	393	1087	2222	3869	6060	12339
1 ,, 50 ...	133	374	1032	2113	3678	5781	11647
1 ,, 60 ...	122	340	944	1932	3364	5296	10787
1 ,, 70 ...	...	313	873	1790	3119	4911	10045
1 ,, 80 ...	...	291	814	1673	2920	4602	9416
1 ,, 90 ...	...	274	768	1575	2752	4338	8893
1 ,, 100 ...	...	260	727	1496	2614	4118	8456
1 ,, 120 ...	...	...	661	1359	2385	3765	7733
1 ,, 140 ...	...	...	607	1256	2202	3479	7148
1 ,, 160 ...	...	...	567	1174	2057	3259	6699
1 ,, 180 ...	...	...	...	1100	1934	3061	6306
1 ,, 200 ...	...	...	...	1041	1827	2896	5962
1 ,, 250 ...	...	...	...	924	1629	2576	5325
1 ,, 300 ...	...	...	...	841	1475	2345	4855
1 ,, 350 ...	...	...	...	...	1361	2158	4460
1 ,, 400 ...	...	...	...	...	1269	2015	4170
1 ,, 450 ...	...	...	...	...	...	1893	3916
1 ,, 500 ...	...	...	...	...	...	1784	3700
1 ,, 550 ...	...	...	...	...	...	1695	3524
1 ,, 600 ...	...	...	...	...	...	1618	3367
1 ,, 700 ...	...	...	...	...	...	...	3075
1 ,, 800 ...	...	...	...	...	...	...	2878
1 ,, 900 ...	...	...	...	...	...	...	2702
1 ,, 1000 ...	...	...	...	...	...	...	2545

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* By Weisbach's formula: see also the "Engineer's Year Book." Crosby Lockwood & Son.

[*To face p.* 40.

CHAPTER IV.

RIVER POLLUTION AND ITS EFFECTS.

Self-purification of rivers—Bacterial purification, by sedimentation, by biological changes—Gross pollution causing nuisance—Ptomain poisoning from polluted waters—Effects of polluted water on oyster culture—Typhoid fever and polluted river water.

River Pollution.—Having described what sewage is, and the various points that have an influence upon its quality and quantity, it would be well to briefly consider the results of pouring it directly into the streams and watercourses.

The Sixth Report of the Rivers Pollution Commissioners deals fully with the so-called self-purification of rivers. The Commissioners came to the conclusion that sewage mixed with twenty times its volume of pure water would only be about two-thirds purified in a flow of 168 miles, at the rate of one mile an hour. They also showed that a 5 per cent. solution of London sewage in highly oxygenated water was, in the course of five days, practically devoid of oxygen, and would therefore be unable to support fish life. It is probable that the Commissioners underestimated the amount of purification which takes place when the pollution is not sufficient to deprive the water of all its oxygen in solution. When the pollution is sufficiently great to deprive the water of all its oxygen in solution, the natural biological cycle of vegetable and animal water life is stopped, and no purification, except by subsidence and decomposition of mud, takes place.

When sewage matter is turned into a running stream the heavier insoluble mineral particles gradually subside, and in falling to the bottom they entangle a certain amount of organic matter, and some purification is thus effected. It is obvious, however, that where the current is not rapid, as in tide-locked rivers, in lakes and mill dams, a certain amount of silting up must occur. The extent to which this takes place will be appreciated when we examine the cost of dredging the Manchester Ship Canal, periodically published in the *Manchester Guardian*. I find that in 1896, 600,000 cubic yards of sludge were removed; 400,000 being contributed by the Irwell, and 200,000 by the Mersey and Bollin.

The nature of the deposit will be seen from the following analysis by Mr. W. Naylor, F.C.S., of the mud taken from Salford dock after being dried at 100° C. :—

Organic matter per cent.	Silica and insoluble matter per cent.	Carbonate of lime per cent.	Oxide of iron per cent.	Alumina and other metallic oxides per cent.
14	77·5	3·6	4·0	0·9

The river Rhone presents an excellent example of self-purification by subsidence. It enters the Lake of Geneva at its head, discolouring its waters for several miles by its rapid, turbid stream. A delta between six and seven miles long has been formed, and is said to be growing at the rate of a mile every five hundred years. Having thus deposited its mud, it leaves the lake a clear blue limpid stream.

Besides subsidence, there is a certain amount of oxidation taking place, particularly in the presence of salts of iron. Putrescent sewage reduces these salts to the ferrous state; ferrous sulphide giving sewage its characteristic black colour. These ferrous salts, in the presence of oxygen dissolved in water, become oxygenated ferric salts once more, to give up their oxygen to the sewage matter and again become ferrous salts. It is probable that nitrates are reduced to nitrites, and nitrites again to ammonia, through the action of putrescent organic matter in the presence of iron salts. Dr. Stevenson also suggests that compounds of iodine act as oxygen carriers.

Leaving the physical and chemical changes which take place when the sewage is added to running water, we now come to the consideration of the biological changes. The bacteriological life in river waters has during the last ten years been made the subject of many investigations in England and America, and on the Continent. The Water Research Committee of the Royal Society, and Dr. Frankland, have published in this country most important contributions upon this subject, more particularly upon the vitality of pathogenic organisms in river water. It is found that the typhoid bacillus and the bacillus of tuberculosis will live in river water for many days, the cholera organism for several months, and the anthrax bacillus for as long as two months.

One point upon which all authorities are agreed is that the number of bacteria in river waters in the summer months is much smaller than during the winter; the reason for this is that during the dry weather the rivers are chiefly formed of spring water, while in the wet season they receive the washings from manured fields, the sewage coming through storm overflows, and the washings from streets and cultivated land.

The bacteria in sewage may amount to almost any number, as many as 30,000,000 to a cubic centimetre having been estimated. From this it will be obvious that one of the effects of turning sewage into a river must be to increase its bacterial contents. The following are the results obtained in specific cases by well-known observers:—

The Derwent.

Above Derby.	Below Derby.
1870.	19440.

The Rhone.

Above Lyons.	Below Lyons.
75 per c.c.	800 per c.c.

G. Roux.

The Saone.

586 per c.c.	4280 per c.c.

G. Roux.

The Spree.

In Berlin.	Below Berlin.
2000 to 20,000 per c.c.	50,000 to 500,000 per c.c.

At Sacrow below Havel Lake.
1500 to 20,000 per c.c. M. Frank.

It should be explained that Havel Lake is seven miles long, and from a quarter to over one mile in width. The comparative great bacterial purity of the river at Sacrow is due to the subsidence and sedimentation in Havel Lake. Prausnitz gives the number of bacteria in the Iser above Munich as 530 per cubic centimetre, while 13 kilometres below the town it is 9111; 22 kilometres away the number falls to 4796; and at Freising, 33 kilometres below Munich, the number is reduced to 2378. The time occupied by the Iser in flowing from Munich to Freising is about eight hours.

Other remarkable instances of the bacterial purification of river waters by sedimentation are recorded by Dr. Percy Frankland;* but all the instances are open to the criticism that the results obtained are not wholly due to subsidence, but are also partly due to dilution. Some 150 varieties of bacilli and 40 varieties of micrococci in their growth attack organic matter and liquefy certain albuminous substances. The soluble products of the decomposition of this organic matter are absorbed by algæ and other plants

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* Frankland, "Micro-Organisms in Water." Longmans.

of low type. These minute forms of vegetable life are the food stuff for rudimentary species of animal life, which serve in turn to nourish the larger animalculæ, which in their turn are the food stuff of fishes. These changes take place only when the water contains oxygen in solution. When the water contains no oxygen other series of bacteria grow in the water, and in their growth, as a rule, produce noxious emanations.

If the sewage is only small in amount, coarse fish live on the particles of fat, etc., which are suspended in it; eels and molluscs too flourish in the mud deposited, and effect a certain amount of purification. Here again, if the pollution goes beyond a certain limit, the fish will disappear, and the purification effected by them will cease. The green weeds, like all chlorophyllous plants, give off oxygen, which in the nascent state is a most active oxidizing agent.

It is not probable that nitrifying organisms grow in water to any great extent, as they require exposure to the air, but in mud the organic matter is attacked by putrefactive organisms, with the result that marsh gas is evolved; bubbles of this gas may be seen rising to the surface of any mud bank of a polluted stream, and in this way a certain amount of purification is effected. If the organic matter contains much sulphur, sulphuretted hydrogen is also evolved. This way of getting rid of the organic matter is most undesirable, as more or less of a nuisance is bound to be caused, and it is merely mentioned as a matter of scientific interest.

The nuisance formerly caused by the discharge of the unpurified sewage of London is notorious. The Metropolitan Sewage Commissioners reported in 1884 that in hot weather very serious nuisance was caused by the foul state of the water, the smell being most offensive, and the water unusable; that the sand dredged near the outfalls, which formerly was pure, was contaminated with foul mud, and that for fifteen miles below the outfalls the fish had disappeared from the river. During the Commissioners' inquiries they had occasion to embark upon the Thames, and three out of the five who went upon the river, together with the clerk who attended them, were attacked during the night of their excursion with severe diarrhœa, which they attributed to the nauseating odour from the river. Of course, nuisance of this kind arises where the sewage discharged into the river is large, and sufficient to use up all the available oxygen in solution in the water.

But it is not necessary for pollution to take place to this extent to become dangerous. In the grosser forms of pollution alluded to, the river water is, of course, unfit for use for any purposes except irrigation. It is not even fit for washing the floors, much less for milk-cooling, for cattle to drink, and the washing of dairy utensils. In this connection it is as well to point out that one of the commonest bacilli in ordinary sewage is the *bacillus coli communis*, the common bacillus of the animal intestine. In a report made to the London County Council by Dr. Andrewes and Mr. Lawes it was shown that the number of these bacilli present in sewage varied from 20,000 to 200,000 per cubic centimetre. As is well known, *bacilli coli* in their life processes elaborate dangerous ptomains, and if water in which these bacilli were present was used for washing out milk-vessels, disastrous consequences from ptomain poisoning might ensue. Similarly mussels from beds which receive sewage give rise to ptomain poisoning. When typhoid bacilli are in the sewage under the above circumstances outbreaks of typhoid fever would follow.

Where river water polluted with sewage is even more dangerous is where it has access to oyster-beds. The Twenty-fourth Annual Report of the Local Government Board contained a supplement on "Oyster Culture in relation to Disease." In this report it was clearly shown that a number of outbreaks of typhoid fever, both in this country and in America, were caused by the consumption of raw oysters, which had been exposed in the fattening-beds to sewage-contaminated water. Indeed, the report goes so far as to say that only a few of the fattening-beds in the country can be regarded as theoretically free from possible chance of sewage pollution.

As instances of the conditions then existing, Cleethorpes may be quoted. These layings, which are among the largest in the country, are situated three-quarters of a mile below one outfall and a mile and a half below the other outfall from Cleethorpes, the two sewers bringing the sewage from a population of about 7500. From one mile to one mile and a half higher up the river than these sewers Grimsby, with a population of 60,000, drains into the river. Similar conditions exist at Southend, Medina river, and other well-known oyster-beds.

One of the well-known outbreaks of typhoid fever due to oysters is that which occurred amongst the students of Wesleyan University, Middletown, Connecticut, U.S.A. This outbreak affected a number of the students and their friends who attended the initiation suppers. The evidence in this case is as follows:—

1. The dates of the cases plainly point to a single source of infection.

2. This source of infection coincides as to date with the initiation suppers.

3. Four guests at the suppers, having no further connection with the College, developed typhoid simultaneously with the cases in the College.

4. The cases of typhoid occurred only amongst those attending three out of seven banquets.

5. Only one article of food was consumed at the three banquets that was not consumed at the other four, viz. raw oysters.

6. Twenty-five per cent. of those who consumed the oysters in question were attacked.

7. These oysters came from a creek 300 feet below the outfall of a sewer discharging sewage from a house where there was typhoid fever.

That the reality of this danger is appreciated by the public will be seen by the fact that the London Fish Trade Association petitioned the Government to ask Parliament to pass a Bill prohibiting the pollution of fisheries, and have invited the co-operation of the various County Councils in the matter.

Where the pollution is of a less gross nature, and the chemist has been unable even to detect it, outbreaks of typhoid fever have still been caused by drinking the water. The best known example of this kind is the now notorious outbreak of typhoid in the Tees Valley investigated by the late Dr. Barry, of the Local Government Board, of which Sir Richard Thorne has well said, "Seldom, if ever, has proof of the relation of water so befouled to wholesale occurrence of enteric fever been more obvious and patent."

The chief facts of this outbreak are shown on the diagram, Fig. 3. The population of the ten Registration Districts affected was 503,616. Of this number 219,435 drank water supplied by water companies who drew their supplies from the Tees, the water being filtered through sand-filters; the remaining population of 284,181 obtained their

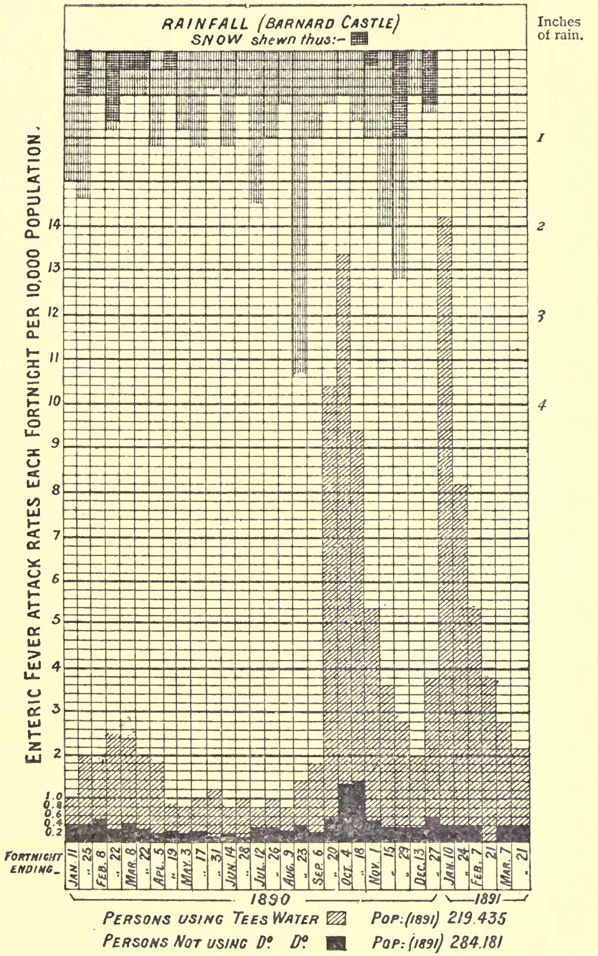

FIG. 3.—Diagram illustrative of OUTBREAK OF TYPHOID FEVER IN TEES VALLEY.

supplies from other sources. The first population had an attack rate of 29 and 24 per 10,000 for the two six-week periods, and the other population had an attack rate of 3·5 and 1·5 for the same periods.

Reference to Fig. 3 will show that the two outbursts of typhoid fever followed closely upon two very heavy rainfalls, which, as a matter of fact, washed out privy-middens and other filth into the river. The total population on the watershed above the intakes of the water companies is about 21,000, of which about 12,000 drain more or less directly into the river Tees.

From the above instances it will be seen that no direct contamination of river water with unpurified sewage, however slight, should be tolerated, particularly above the intakes of any water company.*

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* Cf. page 121.

CHAPTER V.

THE LAND TREATMENT OF SEWAGE.

Sewage farms—Only indicated where soil is suitable—Clay lands nearly useless—The theory of nitrification—Intermittent downward filtration—Irrigation proper—Stratford-on-Avon farm—Edinburgh farm—Paris farm—Berlin farm—Proper method of laying out and working a farm—Quantity of land required—Fallacy of the manurial value of sewage.

Sewage Farms.—Perhaps the simplest method of purifying sewage, and undoubtedly the cheapest and the best where local circumstances permit of its being carried out, is by means of irrigation, by which I mean land treatment alone, including a certain amount of intermittent filtration. Unfortunately, however, it is not everywhere that a suitable soil is to be found, and if it can be found the price may be prohibitive. Nevertheless, the first inquiry to be undertaken with reference to the means of purifying the sewage of any district is to ascertain the nature of the soil and subsoil of the locality. For this purpose the author has found a short boring tool most useful. By means of a rod about four or five feet in length and half to three-quarters of an inch in diameter, made like a cheese-taster, pieces of core within three or four feet of the surface may be obtained. The geological maps are also extremely useful, but their accuracy must not be taken for granted. The best soil for the purpose of purifying sewage by irrigation is an open sandy soil, such as is met with in the Bunter sandstone, or the sandy gravels deposited in many valleys.

The older Authorities complicated the question as to what is the best soil for purifying sewage by trying at the same time to grow a remunerative crop. There can be no doubt that the answer given by the great bulk of the older Authorities to this particular question was the correct one—namely, a sandy or loamy soil, the soil not being of too open a nature. In fact, the soil should be of such porosity that it would absorb at the same rate that it would purify—that is to say, it should not be capable of absorbing more than 25,000 gallons per acre per diem, even if the sewage has the suspended matters first removed by means of precipitation.

But if the purification alone of sewage is aimed at, and no return from crops is looked for, a much more open soil is most suitable; and if the sewage, after undergoing a rough form of precipitation, is only applied intermittently for a few hours and the soil is given a rest for several days before any more is applied to it, a much larger quantity of sewage than this—indeed, as much as 100,000 gallons per diem per acre—can be purified.*

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* Cf. actual working of Stratford-on-Avon intermittent filters, p. 69.

The danger with open soils is that more sewage will be applied than can be oxidized. What is generally taken by the average sewage farm as an indication not to apply more sewage is the fact that the soil begins to absorb less readily. It cannot be too emphatically stated that when this point is reached the land is *overdosed.* Provided, however, that too much sewage is not applied to the land, and if care is taken in this respect, the more open the soil is the better, if it is a good thickness and the subsoil is fine gravel and uniform in texture. Even blown sand on the seacoast will thoroughly purify sewage, if it is applied in small quantities at a time and the application is stopped before the sewage reaches half-way to the land-drains.

It cannot be too clearly understood that there is no relation between the quantity of sewage that can be got to pass through the soil and the quantity of sewage that can be purified; for instance, a thin soil overlying a shaly open rock will take any amount of sewage, but will not purify more than a retentive clay.

The following are some of the formations the soils of which are suitable for purifying sewage: alluvial drift and gravel, the chalk, oolitic sandstones, bunter sandstone, and the magnesian limestone when sufficiently weathered; the old red sandstone, and occasionally the millstone grit.

In almost every formation beds of clay are to be found, and it should not suffice to have one or two trial-holes sunk, but trial-holes should be dug on every side of the piece of land it is proposed to irrigate, and bore-holes to a depth of four feet should be made at intervals all over the site.

The most unsuitable soil, and, unfortunately, one of our commonest, is clay land. It is said that clay lands can be rendered more fit for filtration by ploughing and digging-in ashes, which convert the impervious surface and allow the sewage to sink through. There are in Derbyshire two farms upon which considerable sums of money have been spent in thus preparing the land, in one instance as much as £1123 being spent in lightening 14 acres of land to a depth of two feet with engine ashes. It is perfectly true that this enables the sewage to pass through the clay, but it does not lead to the purification of the sewage, and where the land is a stiff clay it undoubtedly would be better to construct sewage filters.

Clay lands, besides being too impermeable to permit the sewage to pass through them, are unfortunately open to another objection—viz. that in dry weather they crack and fissure, so that the sewage passes directly through the cracks to the land-drains without undergoing any purification. Worms also leave permanent holes in clay, which last for a considerable length of time, and permit the sewage to pass down.

At a small farm at Brampton in Derbyshire the sewage contained a considerable amount of dye-water, and upon a trial-hole being sunk on the said farm, which is a stiff clay, the author found innumerable worm-holes passing directly downwards to the effluent drains, the worm-holes having their sides saturated with dye, and showing how the sewage passed away absolutely unpurified.

Instead of attempting to lighten clay lands where this is the only land available, sewage filters should undoubtedly be adopted.

The researches of Warington, Schloesing, and Muntz, and of the Massachusetts State Board of Health, have shown that the number of nitrifying organisms in soils of sewage filters rapidly diminishes from the surface downwards. Small quantities of soil taken at different depths from the surface at Rothamsted showed that in clay soils no nitrification takes place at a greater depth than eighteen inches; in the most porous soils, however, nitrification still took place at a depth of four feet from the surface. When we bear in mind the quantity of oxygen* necessary for the growth of the nitrifying organisms, these researches only confirm what one would suppose to be the case from general reasoning. It is possible, however, by under-draining very open soils to a great depth, that air may

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* About half the weight of the nitrates produced consists of oxygen.

be taken down deeper and the process be carried on even below four feet.

Fig. 4 shows the number of bacteria per gram of sand at varying depths in a sewage filter, as published in the returns of the State Board of Health, Massachusetts. Reference to the diagram—which is taken from a communication to the Institute of Civil Engineers by C. H. Cooper, C.E.—will show that in the first quarter of an inch the bacteria amounted to over 1,100,000, and at five inches from the surface the number had dropped to about 100,000, so that it will be seen that the great bulk of the changes effected take place in its upper layers.

The change effected by a sewage-filter is identical with that effected by the soil, and reference should now be made to the chapter on Nitrification. The only difference is that when sewage is filtered through land an attempt is generally made to utilize the nitrates that are formed by the nitrifying organisms for the growth of vegetables, grass, osiers, etc. It is only necessary to point out now that the vegetables do not absorb the nitrogen until it is first converted into nitrates, or, at any rate, into nitrites, by the nitrifying organisms.

It will lead to a clearer understanding of the proper method of applying sewage to land to briefly state the method which is usually adopted in filtering sewage. The sewage is applied to the sewage filter for six or eight hours, a penstock at the outlet at the bottom of the filter being partially closed so that the sewage passes slowly and uniformly through the filter, in order that every particle of sewage shall

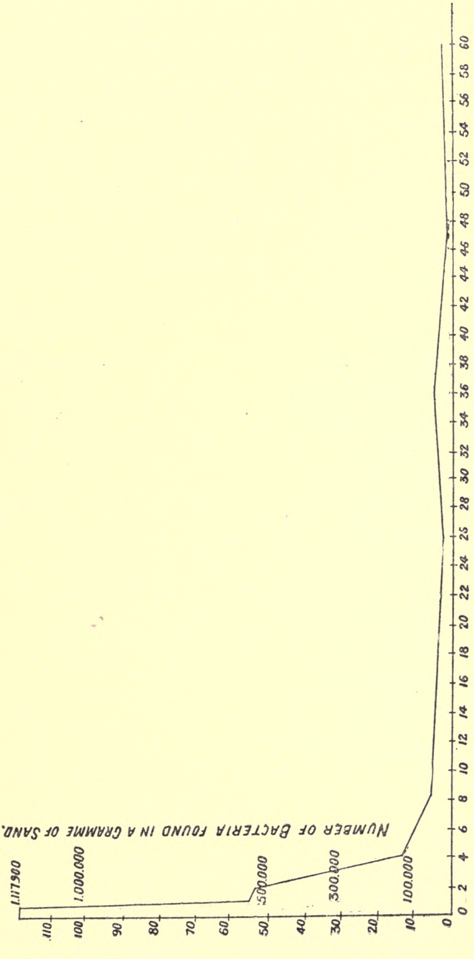

Fig. 4.—Diagram showing Number of Bacteria at Various Depths of Intermittent Sewage Filter.

be brought into intimate contact with the filtering medium. After six hours the penstock is opened wide, and all the sewage is allowed to drain out.

As the filter drains dry, air is drawn into the filter to fill the spaces between the particles of the filtering medium. In this way the nitrifying organisms, growing upon the surface and attached to the particles of the filtering medium, are supplied with oxygen. The whole arrangement is frequently made automatic by allowing the sewage (of course first clarified by precipitation) to accumulate during half an hour in a tank, which automatically discharges by means of a flushing syphon on to the surface of the filter, and by means of a penstock regulate the rate of flow out from the filter, so that the sewage does not run straight through the filter, but the surface drains dry to a depth of about three inches every half-hour. In this way air is drawn into the interstices of the filter supplying the nitrifying organisms with oxygen, and surrounding the particles of which the filter is composed with alternate layers of air and sewage. After the end of the half-hour the tank is again filled, and the syphon discharges the clarified sewage on to the filter again. In this way the vital process of nitrifying bacteria are enabled to be carried on. Such a method of aërating filters could not be carried on unless ventilating shafts from the bottom of the filter are provided to let out the layers of air carried down between the layers of sewage.

Of course if sewage was applied to land every half-hour through day and night all the year round no crops could be grown; but if the soil was open the land would no doubt purify the sewage quite as well as an artificial sewage filter.

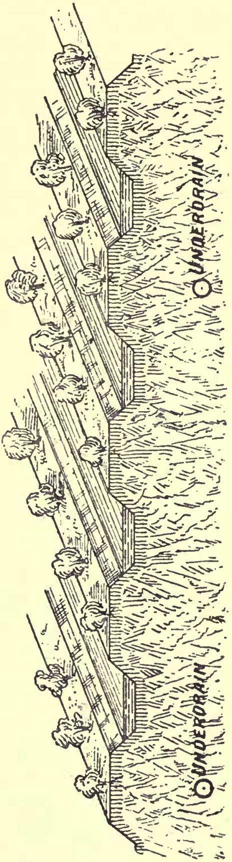

FIG. 5.—METHOD OF PREPARING LAND FOR INTERMITTENT DOWNWARD FILTRATION. —Section on $\frac{1}{8}$th scale.

No hard-and-fast line can be drawn between irrigation and intermittent filtration. The change it is desired to effect is brought about by nitrifying bacteria, and it is the same in each case, except that in irrigation crops are grown on the area irrigated. The sewage being applied with a view of manuring the crops, the surface of the soil is laid out with a uniform fall, so that the sewage will trickle over the surface in a thin layer. In intermittent filtration the surface of the soil is first levelled and then laid out in ditches about eighteen inches wide at the bottom and three feet at the top, the spaces between the ditches being two or sometimes three feet in width, as shown in Fig. 5. In this case crops are grown on the ridges and the ditch is used exactly as a sewage filter.

Intermittent filtration is intensified irrigation. It is, in fact, a compromise between irrigation and the adoption of sewage filters. It is true that crops are grown on the ridges between the ditches, the sewage percolating laterally to their roots. On a properly laid out sewage farm there should be part of the land prepared for irrigation and part for intermittent downward filtration, and it is a good plan to alternate the land which is used for these two purposes, as on the Berlin, Birmingham, and other large sewage farms.

Irrigation Proper.—The usual method of carrying out irrigation is for the sewage to be brought to the highest level of the surrounding land, generally through an underground pipe; from this point it is conveyed through an open earthenware or concrete carrier along a contour; branch distributing carriers being given off in its course. These branch distributing carriers may be allowed to overflow on to the surface of the soil which should be laid out for a uniform fall of about 1 in 100. The actual fall should depend upon the impermeability of the soil. With impermeable soil the fall being even less than this. The final distributing carriers may be merely furrows in the soil itself. With pervious soils far more distributing carriers are necessary to spread the sewage evenly over the land than are necessary with retentive soils.

With regard to stiff clay lands, the best results will be obtained by irrigating twice over, or even more times, as at Leicester, by a catch-water system, as in Fig. 5.

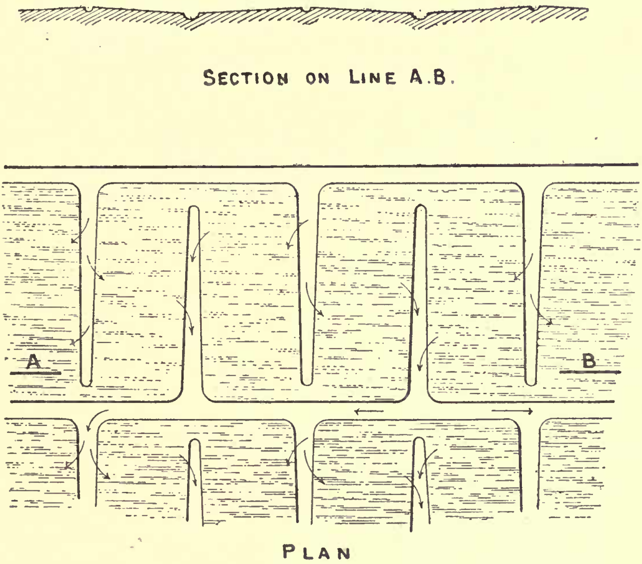

FIG. 6.—METHOD OF IRRIGATING STIFF CLAY LAND.

The arrangement of the distributing carriers must to some extent depend upon the conformation of the land. If it has a gentle slope or is irregular a catch-water system should be adopted, the distributing carriers running along the slope at various levels, the usual distance allowed between two carriers being about a chain; but this distance must depend purely upon the slope and the permeability of the soil, with a rapid slope it being a greater distance, and with a very pervious soil less. When the ground is level, it must be prepared in broad ridges on the ridge and furrow system, the beds being about forty feet wide with the feeder along the top of the ridge.

If the sewage is first clarified by precipitation, from half to one-third of the land otherwise necessary will be sufficient. The actual population the sewage of which can be purified upon an acre of land depends upon the nature of the soil. The author has under his supervision a farm consisting of about forty acres of stiff clay land irrigated with the sewage of a population of 600, the greatest care being used to apply the sewage intermittently; but he has rarely met with a satisfactory effluent therefrom.

When land is irrigated with raw sewage the solid matters in suspension are arrested mechanically on the upper layers of the soil. If the sewage is applied for longer than three or four hours to the same land, the surface nearest to the distributing carrier becomes covered with a layer of slime, which, when the sewage ceases to be applied to the land, dries and forms an impervious film. This not only kills the crops, but also prevents the air from entering the soil and stops nitrification. Where irrigation is adopted, the system used at Berlin—of passing the

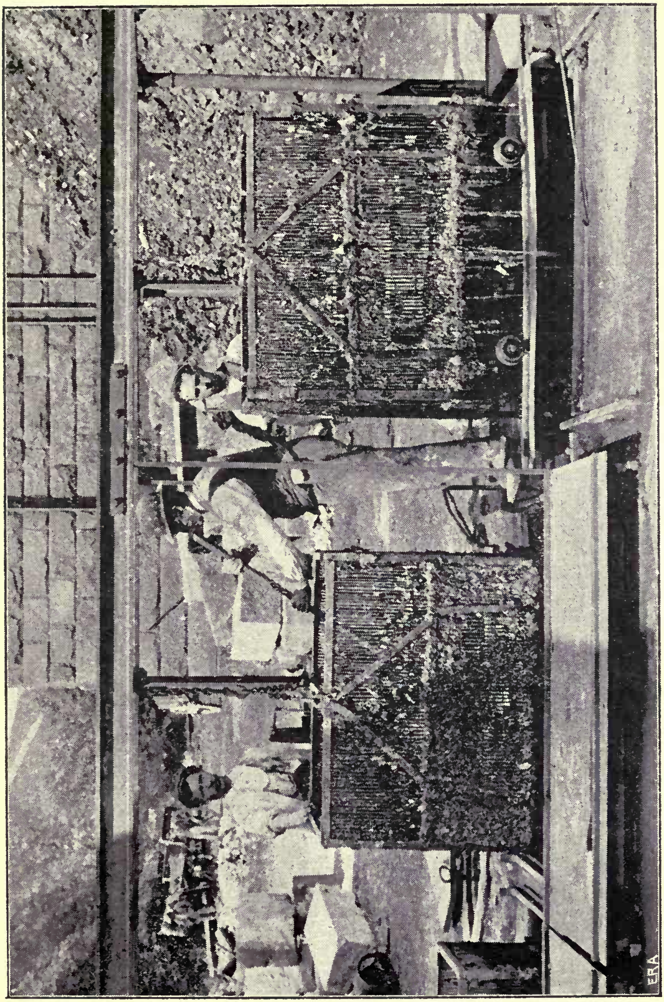

FIG. 7.—CAGE SEWAGE SCREENS, as used at Buxton.

sewage through roughing tanks to allow deposition of the grosser suspended matters—should be taken advantage of; or the sewage should be passed through a series of cage screens, such as are shown in Fig. 7, which arrest a much larger proportion of solids than the ordinary fixed screens.

Unless the land is of a very porous and open nature it will be necessary to do even more than this, either by constructing precipitating tanks and adopting at least partial precipitation, or, what will have the same effect, adding a precipitant to the sewage and allowing it to pass through large carriers in which the suspended matter will be deposited, before applying it to the land.

At Burton-on-Trent sewage farm some five years ago no precipitant was adopted, the result being that the solids in suspension coated the surface of the soil, preventing the sewage from passing in, so that it stood about in big lagoons all over the farm. These lagoons of sewage underwent decomposition, and damages on account of the nuisance caused thereby were obtained by a gentleman who experienced the nuisance at his house five miles away from the farm. As the result of this and other actions brought against the corporation, lime has been adopted as a precipitant. No precipitation tanks have, however, been constructed, the sewage merely running through carriers in the ground for about one hundred yards. In this run, the solid matters in suspension become deposited, and the sewage is at the end of the run perfectly clear; and the soil absorbs it quite readily.

The same experience was obtained at Stratford-on-Avon, where after an injunction had been obtained against the corporation a precipitant was added to the sewage. In this case, too, no precipitating tanks were constructed. After the use of a precipitant it was found that the surface of the land no longer became occluded, and, as a consequence, the sewage no longer lies about in sickening pools creating a nuisance. The following is the method adopted of applying the sewage to the land at Stratford-on-Avon.

The population of Stratford is about 9000, and the volume of sewage about 270,000 gallons a day. At night it is stored in a tank, and pumped on to the land during ten hours each day. Although some fourteen acres of stiff clay land is occasionally irrigated, practically the whole of the sewage is disposed of on nine acres of open sandy gravel, the whole of which has been levelled and is underdrained (the drains being six yards to twelve yards apart); half of it is used for irrigation (so-called), and half is laid out in ridges three feet wide, and furrows one foot wide and nine inches deep, for intermittent filtration. Every year the area in ridges and furrows is levelled, and the area irrigated is converted into ridges and furrows; in this way the land gets well worked up and aërated. Italian rye-grass is grown upon the flat beds, and mangolds and cabbage on the ridges, the sewage only being applied to the furrows. Not a little of the success of the scheme is due to the intermittent manner in which the sewage is applied.

The Stratford effluent contained only 0·056 part of albuminoid ammonia per 100,000, coming well below the provisional standard of 0·100 part which the author has suggested. That nitrification was actually taking place, in spite of an intense frost upon the occasion of the author's visit, is proved by the fact that the effluent contained 1·5 parts of nitrogen per 100,000 in the form of nitrates and nitrites.

The level plot is divided into eight beds, each of which is temporarily divided into four quarters by earthen ridges. The sewage is applied to each quarter intermittently for twenty hours; the bed then has a rest for about six weeks, no sewage being applied. The following is given as the actual time that the sewage was applied to a particular quarter of the bed :—

			Hrs.	Mins.	Hrs.	Mins.
Sunday	8.40 to 9.50 a.m.	...	1	10		
,,	11.30 to 12.0 a.m.	...	0	30		
					1	40
Monday	8.20 to 9.30 a.m.	...	1	10		
,,	12.15 to 1.0 p.m.	...		45		
,,	2.15 to 3.0 p.m.	...		45		
,,	4.30 to 5.0 p.m.	...		30		
,,	6.20 to 7.45 p.m.	...	1	25		
					4	35

	Hrs. Mins.	Hrs. Mins.
Brought forward		4 35
Tuesday, Wednesday, and Thursday, as on Monday, each	4 35	13 45
Total number of hours sewage applied		20 0

After this treatment, no more sewage is put on for six weeks. The sewage delivered through the feed-pipes is 22,680 gallons per hour, so that in the 20 hours 453,600 gallons would be applied to one-eighth part of an acre in six weeks.

By applying the sewage in this intermittent manner for a few hours at a time, air is drawn into the soil between the layers of the sewage (in fact, at Stratford-on-Avon, air could be seen bubbling out of the soil when some fresh sewage was being put on), and not only is the sewage thoroughly purified, but excellent crops are grown on the ridges.*

When a sewage farm is laid out, it should be laid out in plots of a convenient size, which should all be numbered, and a record should be kept in a book to show exactly what plots are being irrigated and the time that they are irrigated for. It is always advisable to have part of a farm laid out as an osier-bed for the reception of storm-water, and it is also advisable to have on the farm a specially prepared

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* I have to express my indebtedness to Mr. A. H. Campbell, the borough engineer, for the above details respecting the method of working the farm.

sewage filter to take the sewage in times of rain, and at such times as the application of sewage to the crops would be injurious. The following diagram (Fig. 8) illustrates the proper method of laying out a sewage farm. A is the detritus tank, B the artificial filter, C the coarse filter for storm-water, D the intermittent land filters laid out in ridge and furrow, E the irrigation area, while the osier bed skirts the river.

With regard to the crops, Italian rye-grass is undoubtedly the best, as there seems to be no limit to its capacity for absorbing sewage; it also grows so closely and so rapidly as to choke down weeds, the seeds of which are brought to the farm in the sewage. Unfortunately, however, rye-grass has to be used freshly cut; it also should not be irrigated for at least ten days or a fortnight before being cut.

Where the sewage farm is large enough for dairy cows to be kept, the difficulty is to a great extent met, because the crops can be cut and consumed on the farm by the cows. Of course, the cows on a sewage farm are kept under cover all the year round. The Corporation of Birmingham have acted on this principle for many years with most satisfactory results. The grass plots should be ploughed up about every three years, and they should be re-sown every spring; as Italian rye-grass and Timothy grass stand the winter very badly.

The next most useful plant for irrigation, particularly on clay and retentive soils, is osiers; and it should be borne in mind that the roots of osiers penetrate

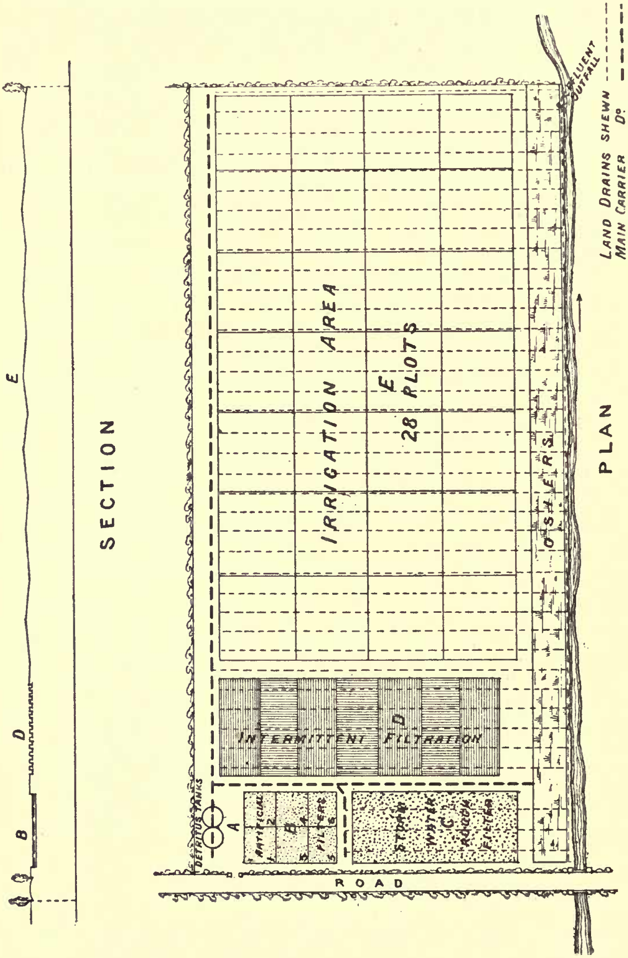

FIG. 8.—Diagram of Method of Laying-out a Sewage Farm.

to a great depth, so that it is of no use underdraining a site on which osiers are to be planted, as the roots soon choke the land drains.

The Local Government Board Committee on the Modes of Treating Town Sewage reported in 1876, that, after rye-grass, cow cabbage and mangolds were the only crops that would continuously take sewage and flourish.

The farm which has the most suitable soil for the purification of sewage within the author's knowledge is that of the Nottingham sewage farm. The Craigentinny sewage fields of Edinburgh are very often referred to, chiefly, perhaps, as instances where sewage disposal works have been made to show a profitable return. The soil here is blown sand, which, before it was irrigated, was perfectly barren; but these fields should never be quoted as sewage *purification* works, as the sewage is applied in great volumes, and it runs away practically unpurified into the drains. The following description of the Craigentinny fields, by Mr. W. Fairley, C.E., is taken from the *Proceedings of the Institute of Civil Engineers*:—

"On the Central or Craigentinny drainage area there are two irrigation farms, both situated on the north-east outskirts of the city, viz. the Lochend of the Craigentinny meadows. Lochend farm has an area of forty-three acres, of which thirty-five acres are commanded by main carriers led from the point at which the main outfall sewer from the city debouches into an open stream. The sewage is pumped up on to the remaining eight acres by an undershot water-wheel driven by the sewage flowing to the lower area. The Craigentinny irrigation farm extends to the foreshore of the Firth of Forth, along which it spreads for a distance of about 1½ miles. This farm, which has an area of about 236 acres, may be taken as typical of the others. The surface of the ground is undulating with a general slope seawards, and a large portion of it was formerly waste land. There is a complete system of under-drainage, consisting of two-inch and three-inch agricultural tile drains, laid ten yards apart and three feet deep. The effluent water of the surface and the under drains is caught by ditches, to be again used in irrigating lower levels, or delivered by the outlets into the Firth of Forth. The secondary carriers divide the ground into plots, each about three-quarters of an acre in area. Four crops are usually taken off the ground annually, and occasionally in dry and favourable years five or six. The ground was originally sown with a mixture of natural and aquatic grasses, the latter in small quantities. The fifty acres under Italian grass are situated at a higher level than the main area of the farm, and are cropped in rotation with the arable land. All these sewage farms are in the hands of private individuals, and they no doubt form a good investment, for after the meadows have been laid out the expenses entailed in the maintenance and management are very small. The grass, which is annually put up in lots and sold by public auction, is readily bought by cowkeepers and dairy-farmers. It cannot be said that these farms play an important part in the *purification* of the sewage. The great bulk of the foul water merely runs over the surface of the ground, and deposits a portion of its suspended matter; but where under-drainage has been provided, the effluent is fairly clear and pure. The presence of the meadows has a tendency to lower the value of land for building purposes in the immediate vicinity. Although no distinct nuisance may arise from them, their near neighbourhood is not free from disagreeable odours.

"The Central or Craigentinny Drainage District comprises an area of 1455 acres, with an estimated population of 107,000, the dry weather sewage discharge being about 800 cubic feet per minute.

"At Portobello, a watering place much frequented by the residents of Edinburgh, frequent complaints were made by the corporation of the pollution of the stream caused by the sewage of Edinburgh, and after litigation the referee recommended that an outfall sewer should be carried direct to the sea with a discharge of the water of Leith outfall.

"By an agreement with the proprietor of the Craigentinny estate, provision had to be made to intercept the sewage discharged on the foreshore from the central outlet of the city, and for this purpose a cast-iron pipe 2 feet 10 inches in diameter was laid across the beach joining the 3 feet 6 inches pipe at an angle of 45 degrees. At the main outlet the sewage is discharged into a strong current, the general set of which is N.E.; any floating matter is therefore carried out to sea, clear of Portobello, and the bathing beaches along the coast."

It must be admitted, however, that what is done at Craigentinny is no criterion inland, or even as to what should be done by an important corporation like that of Edinburgh, even though it has a tidal river to discharge its effluent into.

Another instance of a barren waste becoming a fertile tract of land by being irrigated with sewage is near Paris. The land here, again, is extremely porous and open. In this case, under the unanimous advice of the experts consulted, the Paris municipal authorities decided to dispose of their sewage by irrigation on a neck of land at Genne Villiers. Thirty years ago this land was a mere waste; it is now a fertile market garden. The Authorities have been so satisfied with the results obtained that twelve years ago further land was obtained at Achères. Altogether, Paris has an area of nearly 4000 acres available for the purification of the sewage of its two and a half million inhabitants. This instance is also no criterion for this country, as the rainfall and climate are both exceptionally favourable for sewage farming.

The largest sewage farm in the world is that at Berlin. In March, 1895, the available area for irrigation was 22,881 acres, while the population draining to it is about one and three-quarter millions. The subsoil is sand, with patches of loam and argillaceous loam. The price paid for the land was about £40 per acre. What has made it possible for this farm to be carried on on such a scale, and so well, is the fact that the labour is generally provided by convicts, so that the actual cost of labour on the farm cannot be accurately estimated. Everything connected with the whole of the arrangements is carried on in a manner that would be quite impossible in this country. The day starts with a parade of the sewage men. At six, every man is given his instructions for the day in writing, with a note what the punishment will be if he fails to carry them out. The whole farm is divided into plots of five or six acres in extent, surrounded by roads twenty feet wide and planted with fruit trees. Each plot is further subdivided into so-called "quarters," two-thirds of an acre in extent. The surface of the ground is most carefully levelled to an average slope of one in thirty-three, and upon this slope Timothy and Italian rye-grass are grown. The sewage is brought along the top of the slope, and allowed to flow uniformly over it in a thin layer down the slope. The grass plots are ploughed every four or five years. Before the sewage is allowed to flow over the surface of the slope, it is passed through roughing tanks, or catch pits, as it has been found that the coating of sludge on the land prevents the access of air to the soil, and indeed kills the grass.

The information given above has been extracted from several papers which have been read before the Sanitary Institute and the Institute of Civil Engineers by Mr. Roechling, C.E., who also gives the following details relating to the Berlin sewage farms :—

No. of acres of total area to million gallons of sewage.	Acres actually treated for each million gallons of sewage.	Persons to each acre actually treated.	Persons to each acre of farm.	Gallons of sewage per acre.
372	268	156	112	2687

A large portion of the land is also laid out as intermittent downward filtration beds in ridge and furrow, the ridges being three feet wide and the furrows or ditches eighteen inches deep and two feet six inches wide (see Fig. 5). The sewage is allowed to flow into the ditches until they are nearly full, but not sufficiently high to get on to the top of the ridges so as to soil the turnips, mangolds, and cabbages, which are grown upon them. The solid matter in the sewage falls to the bottom of the ditch or furrow, and impedes the soaking of the sewage through it, the sewage therefore passes laterally to the roots of the plants. The farm has been thoroughly drained on the parallel system in contradistinction to the herring-bone principle, the average depth of the under-drain being three to four feet. The total quantity of sewage being thirty million gallons per day.

The proper method of working a sewage farm is to have about one-eighth of it laid out in ditches for downward intermittent filtration (see Fig. 5, page 61). The site of the intermittent filter should be changed each year, so that the whole of the farm is systematically broken up. The area used for intermittent filtration should be divided into twenty-eight beds, four for each day of the week. Boards, with the names of the days upon which the particular beds are to receive the sewage, should be placed against them, so that any one visiting the farm can at once see that the manager is applying the sewage in accordance with his instructions. The crops grown should be absolutely subservient to the question of purification. The rest of the farm being used for irrigation, the requirements of the crops can, to a certain extent, be considered.

It is also advisable to have a filter capable, in an emergency, of taking the whole of the day's sewage. The filter may be made of crushed stone, coarse sand, or any material which will pass through a three-sixteenths of an inch mesh, and should be under-drained to a depth of four feet. If a sewage filter is constructed it should have a small quantity of sewage applied to it at least twice a week, otherwise it may become dry and the nitrifying organisms upon it perish. Such a filter will be of the very greatest value for use in wet weather, when the crops do not require the sewage, and it will also be useful when the crops are about to be cut. Of course, nothing at all should be grown upon the surface of the filter, not even weeds. The site of the sewage filter will, of course, always remain the same, but the intermittent filtration area should, as I have said, be changed each year, so that the same piece of land becomes an intermittent filter once every eight years. During the time it is being used for intermittent filtration it will store up a considerable amount of manure, which will be utilized while the land is being irrigated.

If the sewage farm is really to do the work required of it, a steam plough is a useful adjunct, so as to break up the surface and to admit the air to a depth of two feet, and in laying out a farm a permanent haulage station, with movable system of cables, should also be devised. In addition, screening arrangements, such as those shown in Fig. 7, and a rough filter for storm water, are necessary.

The conditions under which irrigation alone should be adopted are where there is an open sandy loam or loamy gravel, which can be obtained at a price not much exceeding £150 an acre, and where there is no manufacturing refuse in the sewage which will either cause a nuisance or be detrimental to the crops. Where the land is of a suitable nature, but the price is prohibitive, from half to one-third of the area will suffice if precipitation is also adopted. Whether it is worth while to go to the extra annual expense of precipitation, depends entirely upon the price that is asked for the land. The following Table gives the author's opinion as to the varying quantities of land, with the system which is adopted :—

1. *Irrigation alone.*
    From 1 acre to every 25 persons with stiff clay.
    To 1 ,, ,, 200 ,, ,, sandy gravel.

2. *Irrigation and Intermittent Filtration.*
    From 1 acre to every 200 persons with alluvial drift.
    To 1 ,, ,, 400 ,, ,, sandy gravel.

The one great argument that has repeatedly been used in favour of irrigation, is that the nitrogen of the sewage is utilized by the growing of crops, and that we have in sewage a material source of wealth, the money value of which on theoretical calculations was fixed by the Rivers Pollution Commissioners at about 2*d.* per ton. The suspended matter in 100 tons of average sewage was said to be worth 2*s.*, while the matter in solution was worth 15*s.* Hoffman and Witt, and Lawes and Gilbert, arrived at similar conclusions, while Mr. Bailey Denton put down the value at 1¾*d.* per ton.

Such being the theoretical value of sewage, it was only natural that an attempt should be made to extract its valuable constituents; but as Dr. Tidy pointed out, in a most learned paper read before the Society of Arts, the utilization of sewage must be distinguished from its purification—they are totally different questions. It is true that sewage may be poured in enormous quantities upon crops growing upon an open soil, such as blown sand, and that under these circumstances a certain proportion of the valuable constituents of sewage would be utilized, but the sewage must be poured on in such quantities that little purification will be effected. When the nitrogen, as nitrates and nitrites in a good effluent, is estimated, it will be found that the crops have taken up a very small percentage of nitrogen indeed. In addition to this, it is doubtful whether all the nitrogen taken up is derived from the crops. The researches of Nobbe and Hiltner on leguminous plants have shown that by the aid of certain bacilli small tubercles are formed in the roots of the leguminous plants which enable them to take up nitrogen from the air.

In many of the cases which have been quoted as instances where the total nitrogen has been greatly diminished in passing sewage through land, and where it is assumed that the nitrogen has been absorbed by the crops, it will be seen that the chlorine has also diminished, the fact being that the sewage has become diluted with subsoil water. The analyses published by the British Association of the sewage and effluent from Breton's farm, Romford, the Croydon farm, and Merthyr Tydvil, are all open to this criticism. It also applies to Sir Edward Frankland's experiments on the Barking farm, as reported in 1871. In this case 70 per cent. of the nitrogen came away in the sewage; but it is wrong to assume, as has been done, that the other 30 per cent. of the nitrogen was absorbed by the crops, for the chlorine was diminished 34 per cent., an amount which certainly could not be absorbed by vegetables, and a figure which clearly shows that the effluent was greatly diluted with subsoil water.

It can be shown that there is a considerable amount of ammonia in smoke, and when urging upon manufacturers the necessity for using smoke-preventing appliances, this fact has ingeniously been adopted as an argument why black smoke should be allowed to continue or even be encouraged. The argument is quite as sound as that of the money value of sewage.

When the English reports as to the money value of sewage went across the Atlantic, Forbes replied to them by asking, if a bottle of brandy were poured into a barrel of water, whether the mixture would be worth as much as the original brandy; while Professor Storer pointed out that Philadelphia stands upon a bed of clay which contains a pound of gold in every 1,224,000 pounds. From which data, the money value of the gold in the clay within the limits of the city of Philadelphia is not less than 100,000,000 dollars, but no one would dream of attempting to extract it. These American criticisms are strictly to the point. Agriculturists can get chemical fertilizers in a form in which they can be readily used for less money than the labour costs to apply the sewage in a manner in which it can be absorbed by the crops.

We must not lose sight of the fact that the nitrogen in the sewage has to be converted into nitrates, or nitrites, before it is assimilable by the crops, and to do this it must be applied with equal volumes of air, and the cost of the labour in so applying it must be taken into the estimate. Liebig's fantastic picture of Britain as a vampire on Europe, sucking out its life-blood and pouring it into the sea, was conceived without taking into consideration the fact of the enormous quantities of nitrogen which annually are imported into the country in the form of beef, mutton, corn, and nitrates, nor did it take into consideration the enormous quantities of carbonate and sulphate of ammonia, annually manufactured in the country at the various gas-works, which are now used as fertilizers.

When we bear these facts in mind, and also that leguminous plants have the power of absorbing nitrogen from the air, and that the sea requires its nitrogen replenishing, on account of the fish taken from it, the fallacy of the manurial-value argument becomes too ridiculous to entertain for one moment.*

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* Since the above was written, Prof. Crookes has endeavoured to resuscitate the nitrogen bogey, with the evident intention of showing how easily it could be laid low, by utilizing the nitrogen of the air as a source of nitrates.

CHAPTER VI.

PRECIPITATION, PRECIPITANTS, AND TANKS.

Limitations of the process—In practice solid matters only removed—Soluble matter removed by excess of precipitants—Comparative costs of precipitants—Lime, alum, copperas—Various patent precipitants—Precipitation without tanks—Absolute rest tanks—Continuous-flow tanks—Dortmund tank of Kinebühler—The Candy tank—Sludge, and methods of dealing with it.

By precipitation is meant the deposition of the insoluble matter in suspension in sewage, together with a certain proportion of the organic matter in solution, by the addition of some chemical which forms insoluble compounds with it, and at the same time deodorizes it. For a considerable time it was claimed by one school of experts that by precipitation sewage could be sufficiently purified to be discharged into any river, while a rival school advocated the claims of land alone. To-day the limitations of each are recognized, and it is generally admitted that by precipitation practically only the solid matter in suspension is removed.

The chemicals which have been used for this purpose are almost innumerable; but only three need seriously be considered, viz. alum, copperas, and lime, or some combination of these. Most of the precipitants sold under fanciful trade names are composed of these substances in varying proportions. The general plan of the process of precipitation is for the chemical to be added to the sewage; the mixed chemical and sewage is then well mixed up by means of water-wheels or baffling plates. The mixture is then allowed to flow into a large precipitation tank, where it is either allowed to rest for a few hours, or is passed continuously through the tank at such a slow rate of velocity that the suspended matters fall to the bottom of the tank, where they form a dark sludge, containing about 95 per cent. of water; the clarified effluent overflowing from the tank. Details of different forms of precipitation tanks are given on a subsequent page.

The use of lime as a precipitant has been much prejudiced by the reports which have been published on the so-called "lime process" as it was carried out years ago, the effluent from the precipitating tank merely being passed into the river without any irrigation or filtration. It should be at once clearly stated that the effluent obtained by any process of precipitation is not fit to be turned into a stream without subsequent biological filtration. For practical purposes, it may be assumed that the precipitation process will merely remove the solid matters in suspension. It is true, as Mr. Dibdin has shown, that in the laboratory from 10 to 30 per cent., and even more, of the organic matter *in solution* can be removed; but it is a safe rule to assume that in the working of a sewage purification scheme by precipitation the suspended matters only are removed.

The following Table gives the results obtained by Dibdin with various precipitants upon the organic matter *in solution* in the Metropolitan sewage. The results are expressed as a reduction per cent. in the oxidizable organic matter:—

REDUCTION OF *SOLUBLE* ORGANIC MATTER BY VARIOUS PRECIPITANTS.

Grains per gallon of precipitant used.		Percentage of purification.
3·7	of lime *in solution*	11
5·0	,, ,,	15
10·0	,, ,,	19
15·0	,, ,,	25
3·7	,, ,, and 2·5 of iron sulphate	18
3·7	,, ,, 5·0 ,, ,,	21
5·0	,, ,, 10·0 ,, ,,	25
10·0	,, ,, 10·0 ,, ,,	30
5·0	,, ,, 5·0 of sulphate of alum	18
28·0	,, ,, 20·0 ,, ,, 6·0 of sulphate of iron	24
56·0	,, ,, 40 of sulphate of alum and 12 of sulphate of iron	31

In addition to Mr. Dibdin's experiments, the Massachusetts State Board of Health have made careful experiments on the relative value of various precipitants, and the proportion of organic matter *in solution* removable by them. The following Table gives in a condensed form some of the most practical of their conclusions, the quantities of the precipitants used being in each case of the same value, about 1*s.* 3*d.* per annum per head of the population dealt with :—

Crude sewage yielding 0·40 part per 100,000 of organic matter.
„ after settling 0·28 „ „ „ „
„ „ straining 0·26 „ „ „ „

After precipitation with—

	Organic ammonia per 100,000.	Reduction of soluble matter per cent.
1800 lbs. of lime per million gallons	0·19	0·22
1000 lbs. of copperas and 700 lbs. of lime per million gallons	0·17	0·29
400 lbs. of ferric sulphate	0·15	0·32
650 lbs. of alum sulphate	0·19	0·20

With regard to lime, what takes place when it is added to sewage is that immediately carbonate of lime is formed; this acts as a weighting material, entangling the flocculent matters in suspension and carrying them down to the bottom of the tank with it. The lime also forms an insoluble compound with a certain amount of organic matter in solution, which also is carried down.

There is no doubt that the carbonic acid in the sewage holds a lot of carbonate of lime in solution, and if the tank effluent is allowed to pass into any stream with a short run the carbonic acid is given off, and the carbonate of lime is deposited as a white insoluble substance in the river. This is what is sometimes called the secondary decomposition of lime effluents. If, however, the tank effluent obtained from precipitation with lime is irrigated over a large area, the carbonate of lime is deposited in the soil, and is also split up by the nitric acid formed by the nitrifying organisms, a stable nitrate of lime being formed in its place, and no secondary decomposition will result.

Another objection which there was to the use of lime as a precipitant, without subsequent intermittent filtration, arises from the danger of the sewage being overdosed, so that some free lime might escape into the rivers and thus kill the fish. Wherever lime is used the following conditions should be complied with—

1. An indicator, such as phenol-phthalein or nitrate of silver, should be used, and the lime should only be added until the sewage becomes barely alkaline.

2. The lime should be ground and added as a saturated lime-water.

3. Mechanical agitation of the sewage with lime-water should immediately take place.

The sludge should be removed if possible *each day* from the precipitating tanks. It soon putrefies and rises in large pieces, setting up decomposition of the supernatant sewage, thus undoing the good done by chemical treatment.

There are three classes of sewage for which lime is particularly suitable.

1. Sewage containing salts of iron and mineral acids, such as the sewage from Birmingham, Sheffield, and Wolverhampton. With this class of sewage, the lime has the advantage that it neutralizes the acid which would otherwise absolutely prevent nitrification; it also combines with the iron salts and forms hydrated oxide of iron, which acts also as an excellent precipitant.

2. Sewage containing the refuse from breweries. Brewery waste contains a large amount of carbonic acid and yeast cells which produce carbonic acid. This with the lime forms the insoluble carbonate previously alluded to. The sewage of Burton-on-Trent is precipitated with lime, as much as thirty to forty grains to the gallon being used.

3. Sewage containing dye wastes. In some instances it may be necessary to also add a small proportion of copperas in this case.

With all precipitation processes the sewage should be got to the outfall works as soon as possible, so that as much organic matter as can shall be retained as suspended matter. For the same reason, when it is necessary to pump the sewage for the purpose of filtration, *this is best done after it has gone through the precipitation tanks.*

For *small* schemes it is practically impossible to use lime as a precipitant, on account of the necessity for expensive machinery to grind it. The commonest precipitant used in this country for small schemes is alum. Spence's alumino-ferric blocks is a favourite method of employing it. These blocks are merely suspended in the sewage, and as the flow increases more of the precipitant comes in contact with the sewage and is dissolved, precipitating the fatty and albuminous matters to the bottom of the tank as sludge. This precipitant costs from £2 10*s.* to £3 per ton. The quantity necessary to precipitate the suspended matter is from 10 to 20 grains per gallon, and by reckoning 15½ grains * per gallon as equivalent to a ton per million gallons, the cost can easily be calculated.

The various chemicals which have been suggested for use as precipitants are innumerable. Many of them are combinations of alum and iron salts and lime. The following is a list of some of the most known precipitants :—

Name of Precipitant.	Chief Ingredients.
Ferrozone	Crude alum, copperas, and magnetic oxide.
Alumino-ferric	Crude alum, with a trace of iron salts.
A. B. C.	Alum, blood, and clay. The alum and the clay are the useful ingredients. Probably as good results would be obtained by the alum alone.
Amines process	Lime and herring brine. Large quantities of lime are used, and the temporary sterilizing of the sewage is, no doubt, due to it.

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* A ton actually contains 15,680,000 grains.

Name of Precipitant.	Chief Ingredients.
Bacillite process	A disinfectant, such as carbolic acid, is used as well as a precipitant. The germicide, if real, would also kill the nitrifying organisms, so that this process, like the amines, should not be countenanced if it really is a sterilizing process.
Hanson's process	Black ash waste, consisting of salts of soda and sulphide and sulphite of lime. The precipitant will have to be oxidized before nitrification can start, and it is probable lime alone would be as efficient.
The phosphate process ...	Phosphate of alum in hydrochloric or sulphuric acid. The idea was that a triple phosphate would be precipitated, the ammonia thus being trapped, as it were. The value of the ammonia obtained in practice does not compensate for the phosphate lost.
The electrolysis process ...	The sewage is electrolysed, oxygen being liberated ; this partly attacks the organic matter and partly the iron plates at the negative pool, forming iron salts, which act as a precipitant. The iron salts can be added cheaper as copperas in the ordinary way.
The Hermite process ...	Electrolysed sea-water, containing free chlorine, is added to the sewage, with the view of sterilizing it. (See remarks on Bacillite process.)

Precipitation without Tanks.—At Stratford-on-Avon and at Burton, the experiment is being tried of adding a precipitant without any precipitation tanks. As far as Stratford-on-Avon is concerned, the experiment is quite successful. The solids in suspension are thrown down upon the surface of the land and are dug in. At Burton-upon-Trent the same method is being adopted, but here the enormous quantity of sludge deposited is deteriorating the porosity of the land. The late Dr. Tidy was responsible for the Stratford-on-Avon experiment, while the Burton experiment (where thirty to forty grains of lime per gallon are employed) is due to Professor Dewar. Before the sewage was limed at Burton, the slimy sludge was carried *all over* the surface of the land, covering it with a sticky albuminous film. Since a precipitant has been used the sludge is deposited on a limited area, and the sewage at present passes freely through the land. But where a precipitant is used, and there is not a very large area of land, tanks of some kind or other must be constructed.

For the success of precipitation processes, besides the sewage being fresh and as little broken up as possible, it is necessary that the precipitants should be got into very intimate union with a small portion of the sewage, and that this should then be mixed carefully with the whole of it.

The tanks must be adequate in size. Their actual capacity in any case will depend upon whether they are to be used on the absolute rest principle or continuously; if for absolute rest for six or eight hours, the tanks must be in triplicate, and should hold at least a day's sewage.

Absolute Rest Tanks.—These tanks can only be used without pumping where there is an available fall of six or eight feet for the precipitation portion of the process of purification. As a fall of six or eight inches only is required in continuous tanks, and any extra fall which is available can be utilized to greater advantage by filtering twice over, I do not think that absolute rest tanks will be used to any extent in the future.

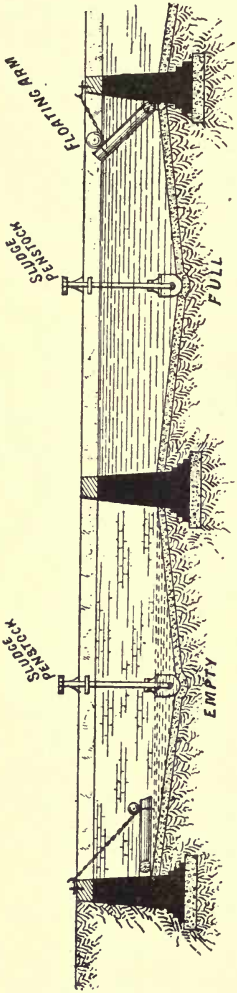


Fig. 9.—Complete-rest Precipitation Tanks.—Section on $\frac{1}{16}$th scale.

Where there is such a great fall at the outfall works that absolute rest tanks are decided upon, the best arrangement is as sketched in Fig. 9; it will be seen that the clarified sewage runs out through a floating arm near the bottom of the tanks, thereby requiring a considerable fall.

The illustration (Fig. 9) shows the ordinary complete rest precipitation tanks in the various stages of the process of purification. No. 1 is being emptied by means of a floating arm, the outlet of the floating arm is about four inches below the surface, and falls with the level of the sewage. The result is, that the sludge and the scum are both left in the tank, and only the clarified sewage is decanted. The sewage is commanded by a valve, which prevents it escaping through the floating arm. The sludge is let off by the sludge penstock being opened. In the process of filling, the sewage runs down a floating salmon ladder to prevent the sludge being stirred up.

Where there is not more fall than two or three feet, the precipitation must take place in a continuous-flow tank, and in this country, until the last few years, the arrangements for removing the sludge have been of a most unsatisfactory nature. *First of all it has been necessary to have the tanks in duplicate, and, under certain circumstances, in triplicate, then it has been necessary to pump off the tank effluent before the sludge could be removed.*

Continuous-flow Tanks.—The Conical-bottomed Dortmund Tank of Carl Kinebühler.—The credit for first getting over these difficulties is due to Carl Kinebühler, for although the tanks designed by him and adopted at Dortmund and subsequently at the Chicago Exhibition, and during the last three years, with slight modifications, at numerous places in England, have not proved absolutely satisfactory when only used singly, yet, compared with the alternative of the old-fashioned, flat-bottomed, continuous-flow tank, they possess advantages which make them immensely superior, and when constructed in duplicate, with arrangements for emptying them when necessary, they leave little or nothing to be desired.

The drawbacks to them are said to be—

1. The sludge does not always gravitate to the bottom of the cone.

2. As the sides are not thoroughly cleaned, colonies of bacteria form, and are carried off in the tank effluent.

With regard to the first objection, I have in my district about a dozen conical bottomed tanks, and I can emphatically state, if the sludge is removed daily, this difficulty does not arise. On the other hand, some of the most solid sludge I have ever met with has come from tanks of this description, and contained as much as 7 per cent. of solid matter.

With regard to the second objection, that, after a time, colonies of bacteria pass over in the tank effluent, so as to injure the filters, I must corroborate this ; but it is a difficulty which could be easily overcome by the adoption of a revolving scraper, of a rapid screw shape, which, by being slowly revolved each day, at the time the sludge was being pumped out, would remove the slime from the sides of the tank, and wind it down to the apex of the cone. Another way of obviating this difficulty is to have at the outlet a series of perforated pipes four inches below the water level, across the tank, or to have the tanks in duplicate.

But whether the conical bottom survives in the process of the evolution of a perfect precipitating tank or not, the apparently paradoxical continuous upward flow of the sewage, with a downward movement of the sludge, is an innovation which has come to stop.

There is in these upward-flow tanks a neutral plane at the level of the point, where the velocity is so slow that the particles precipitated cannot be carried on. Each particle of the coagulum arrests another in its upward path until, growing as a rolling snowball does, there is across the whole tank a floating meshwork of flocculent matter, which acts as a kind of strainer.

That this is so, I have proved by watching the process in a small tank constructed of glass, and I have also frequently passed a glass tube down a precipitating tank, and, on drawing it up, have found the precipitation all confined within levels twelve to eighteen inches apart. The following diagram of the Dortmund tank clearly explains the method of working it:—

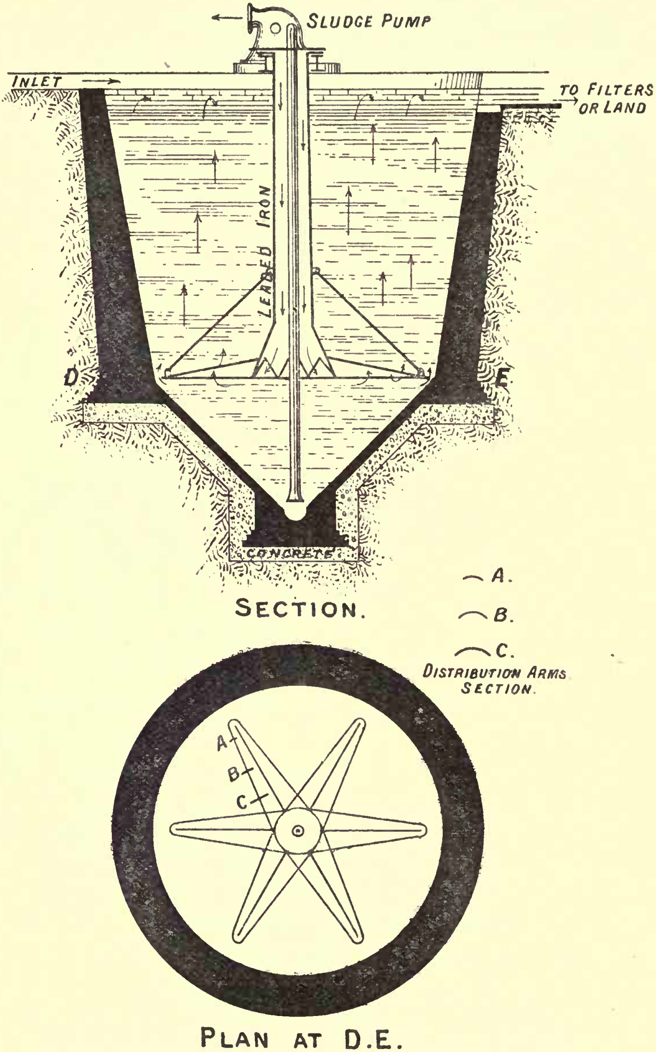


FIG. 10.—IMPROVED DORTMUND TANK.—Scale 8 feet to the inch.

The Candy Tank.—The upward-flow principle has been adopted by Mr. Candy in his circular flat-bottomed tank. This tank permits of the sludge being removed without first pumping off the supernatant tank effluent; this can be done by gravitation where there is a fall of about eighteen inches.

The author has two of these tanks in his district, and has carefully watched them for the last two years. They act admirably if the sludge is removed daily. The sludge, which, in his experience, contains about 97 per cent. of water, is removed by revolving a perforated sludge-pipe, which is pivoted at the centre of the tank floor, and by means of a worm gear sweeps all round the bottom of the tank; the outlet of the sludge-pipe is made to discharge eighteen inches below the level of the sewage in the tank, and when the screw-down valve is opened, the head of eighteen inches of water in the tank is sufficient to force the sludge through the perforations and up the sludge-pipe. When the sludge begins to run thin, the man in charge slowly winds the revolving perforated arm round, until one complete revolution has been made, by which time the whole of the sludge lying on the bottom of the tank will have been picked up. Attached to the revolving perforated sludge-pipe is a rubber scraper, which, by the same mechanism as moves the sludge-pipe, scrapes the sides and bottom of the tank, thus preventing the growth of colonies of bacteria, which is one of the drawbacks to the Dortmund tank.

The International Sewage Purification Company have also applied the same principle of extracting

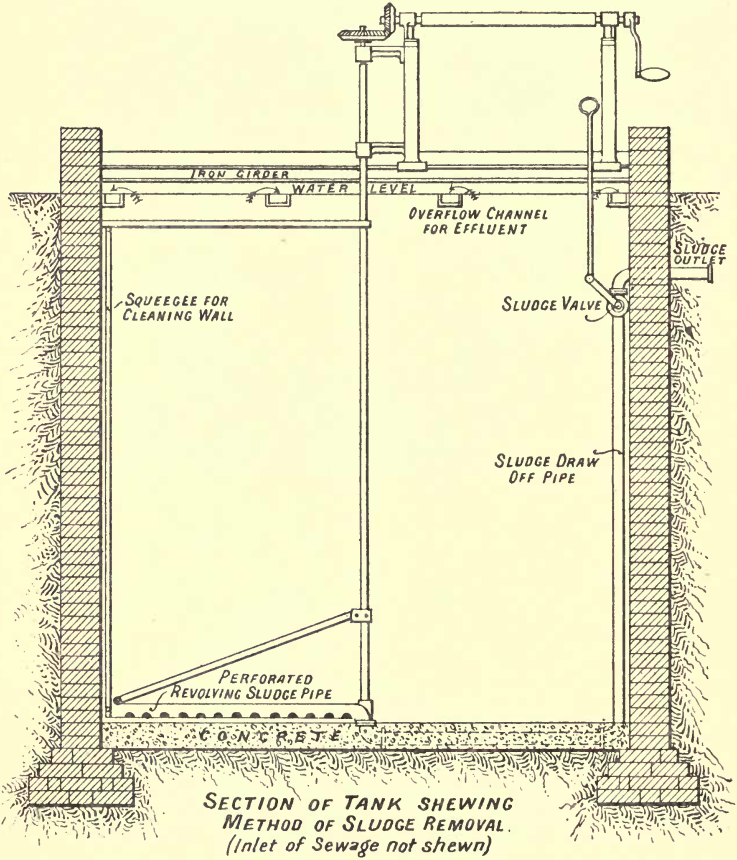


Fig. 11.—The Candy Tank.

sludge to rectangular tanks, the perforated arm travelling from one end to the other on a tramway.

Perhaps the latest form of tank which permits the sludge to be removed without first pumping off the tank effluent, is what may be called the "travelling squeegee" tank. In this, the sludge is forced down to the deep end of the ordinary rectangular continuous-flow precipitating tank, by means of a slowly moving squeegee, which travels on rails laid on the bottom of the tank. When the squeegee has been brought within about three yards of a perforated sludge-pipe, lying at the deepest part of the tank, the sludge outlet is opened, and the squeegee moved up gradually to this pipe, as the sludge flows out about eighteen inches below the top water level. The squeegee is then wound back to the top of the tank, where it stays till the sludge is removed, the next day.

There are several other precipitating tanks, such as the "Ives," a modification of the ordinary Dortmund tank, but not (to the author's mind) an improvement on it. There are others which need not be mentioned, as one has no word of approval for them.

With regard to the percentage of purification effected by precipitation, having taken the average of some twenty precipitation tanks in his district, the author has found that the purification effected by alumino-ferric on ordinary domestic sewage is about 60 per cent.

With regard to the precipitant to be adopted under various conditions, with ordinary domestic sewage, where there is a large proportion of soapy slop water, nothing could act better than alum. Spence's alumino-ferric cakes acting on such sewage in a Dortmund tank gave the following results :—

	Organic ammonia, parts per 100,000.
Before precipitation	0·88
After ,, ...	0·36

For sewage containing mineral acids or brewery wastes, lime is the most suitable precipitant. For sewage containing dye waste, copperas and lime, and for sewage containing tannin, copperas, alum, and lime will probably be required. The exact proportions of these various ingredients will vary with the particular sewage.

To show how commonly precipitation is now adopted in addition to irrigation, a return made to Parliament in 1894 showed that this process was adopted at as many as 174 places.

In sixty cases the return also gives the nature of the precipitants used, and from it I have constructed the following Table, showing the nature of the chief precipitants in use, and the number of places at which they were adopted :—

Lime.	Alumino-ferric.	Lime and alumino-ferric.	Ferrozone.	A.B.C.	Alum.	Iron, salts, and lime.	Lime, alum, and copperas.
20	11	8	9	2	4	5	1

Sludge.—After the sludge has been removed from the precipitating tanks, in small schemes—that is to say, in schemes for populations of less than 5000, and where the outfall works are far removed from houses—it is sufficient to allow it to dry in trenches about one foot deep and one yard wide, the trenches being covered at the bottom with ashes, and having a drain leading back to the precipitating tanks. In this way the liquid part of the sludge is got rid of, and in a few weeks' time it dries into a friable cake, which makes an excellent top-dressing for grass, but is not of such value that it can be sold.

For larger schemes, special areas of land will have to be set apart for drying the sludge upon, and then movable carriers will have to be provided for turning it upon the different parts of the land. This method of removing the sludge has been successfully worked at Birmingham for many years, and it is distinctly indicated wherever there is any low-lying land, the level of which it is desirable to raise, and there are no houses within a few hundred yards of the sludge-drying area.

The sludge is also useful for embanking rivers to prevent storm waters from overflowing the land.

Another method of dealing with it very commonly in vogue, particularly where the works are close to habitations, is to press it with a filter press. This press consists of two folds of jute or other coarse fabric, spread between plates of iron, whose surfaces are grooved; the sludge is forced through the jute by means of compressed air, and the water is blown out, leaving the solids between the two layers of jute as a cake of sludge about one inch in thickness and a couple of feet square.

Unfortunately this method of dealing with the sludge is somewhat expensive, the cost of the process working out at about 2*s.* 6*d.* per ton, and even more where lime is not used as a precipitant. This is irrespective of depreciation of plant and loss of interest on capital. For this 2*s.* 6*d.* per ton, about 16 cwt. of water is extracted from the sludge, and it has this one advantage that it can be removed in carts without slopping on the roads or causing any nuisance.

Most of the English authorities on sewage disposal state that the sludge "from any system of sewage disposal consists of about ninety parts of water and ten parts of solids." The sludge which has been allowed to drain dry in the old-fashioned flat-bottomed tanks might possibly have this composition; but as sludge is removed from precipitation tanks it rarely contains less than 94 per cent. of water; indeed, one would be inclined to say that average sludge contained about 95 per cent. of water—that is to say, only half the solid matter it is generally supposed to contain. Sludge removed from the Candy tank contains about 97 per cent. of water and 3 per cent. of solid matter, while that from the conical-bottomed Dortmund tank contains from 93 to 95 per cent. of water, and from 5 to 7 per cent. of solids.

It should be understood that these percentages refer only to the sludge as removed from the tanks; after it has been standing a little while the water would separate, and the residue would undoubtedly only contain 90 per cent. of water and 10 per cent. of solids; after pressing, the sludge contains from 55 to 60 per cent. of water, while air-dried sludge from Birmingham or other places contains about 12 or 15 per cent. of water.

If, therefore, sewage disposal works have sufficient land—some 200 or 300 yards from dwelling houses—for the sludge to be dried upon, this method of dealing with it is cheaper and more satisfactory than by pressing it; as, after pressing, there is still a mass of solid cake equal to one-fifth the bulk of the original sludge to be got rid of, and, in the author's opinion, it is not as a rule worth paying 2*s*. 6*d*. per ton to get this comparatively small benefit. Where, however, for any special reason the sludge is offensive, it will probably be necessary to adopt pressing.

CHAPTER VII.

FILTRATION OR NITRIFICATION.

Intermittent land filtration—Artificial filters suggested by Warington in 1882—Conditions necessary for nitrification—Experiments by the Massachusetts Board of Health with coarse sand, fine sand, peat, silt, garden soil, and fine gravel—Results obtained — London County Council experiments — Results obtained.

In the First Report of the Rivers Pollution Commissioners, in 1870, mention is made of downward intermittent filtration of sewage through land, and a number of experiments on the filtering capacity of different soils were carried out.

As the result of laboratory experiments of Sir Edward Frankland, the following conclusions were arrived at :—

1. That the soil should not be too open, so that any quantity of sewage could pass through.

2. That it should be deeply drained to a depth of six feet.

3. That the sewage should be dealt with intermittently.

In the Second Report of the Rivers Pollution

Commissioners, intermittent filtration was defined as "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."

Frankland claimed that one acre of land laid out as an intermittent filtration area was sufficient for a population of 3000 or 4000, or for from 50,000 to 100,000 gallons of sewage a day, the land being divided into about twelve parts, each part receiving successively the whole of the sewage for about six hours. In practice, it was found that intermittent filtration areas could best be worked by land laid out in ridge and furrow, and by growing crops on the ridges, with open sandy soil, worked as a sewage filter without any regard to cropping, possibly this quantity might be purified after precipitation.

At Merthyr Tydvil and at Kendal, this estimate was tried on a practical scale, and it was found that a population of 1000 to the acre was all that could be efficiently dealt with.

The analyses of the sewage before and after filtration at Merthyr Tydvil are not comparable, because a very large quantity of the subsoil water finds its way into the subsoil drains, and dilutes the effluent, apparently giving a percentage of purification which is quite unwarranted.

At Kendal, some 750,000 gallons of sewage, half of which is subsoil water, are dealt with each day by downward intermittent filtration. In the first instance, upon 5½ acres of filter, and subsequently it was found necessary to acquire another 11½ acres.

These two instances of intermittent filtration were carried out some twenty years ago, and since then, intermittent filtration areas have been laid out on most sewage farms, notably at Nottingham and Birmingham. At the latter place, it has been found that, with a gravelly subsoil, the limit of the population that can be dealt with is about 500 to the acre, even after the solid matters have been removed from the sewage by precipitation.

The next step in the evolution of the present biological sewage filter was due to Warington, who in 1882 communicated a paper to the Society of Arts, and pointed out that dilute solutions of ammonium salts or of urine would not undergo nitrification if they were sterilized by boiling, or by the addition of antiseptics, and were supplied with air which was filtered through cotton wool. If, however, a small particle of fresh soil were added, in a little while active nitrification would set in. He further found that this process went on best in the dark, that an alkaline base such as lime was necessary, and a temperature ranging from 40° to 120° Fahr. He further called attention to the researches of MM. Schloesing and Muntz, who claimed that nitrification proceeded with the greatest rapidity at a temperature of 99° Fahr. Warington in his article wrote—

"Though, however, porosity is by no means essential to the nitrifying power of a soil, it is undoubtedly a condition having a very favourable influence on the rapidity of the process; a porous soil of open texture will present an immense surface, covered with oxidizing organisms, and generally well supplied with the air requisite for the discharge of their functions. . . . A filtering medium of pure sand and limestone, treated intermittently with sewage, will, after a time, display considerable nitrifying powers, the surfaces becoming covered with oxidizing organisms derived from the sewage. . . . It will be gathered from the observations now made, that it would be possible to construct a filter bed, having a greater oxidizing power than would be possessed by an ordinary soil and subsoil. Such a bed would be made by laying over a system of drain pipes a few feet of soil, obtained from the surface (first six inches) of a good field, the soil being selected as one porous and containing a considerable amount of carbonate of calcium." (See Fig. 12.)

This important suggestion of constructing artificial nitrifying beds or filters lay in abeyance for many years, and was first carried into effect for the purification of large quantities of sewage by the International Sewage Purification Company. The only difference between the filter which Warington suggested and that which the Company constructed was that, instead of using sand and limestone chippings, this Company adopted sand and a magnetic oxide of iron prepared by being roasted with carbon in a closed chamber,

—a preparation which they sold under the trade name of Polarite.

These new artificial filters were tried for eight hours and then allowed to have a rest of sixteen hours. When the quantity of defœcated or clarified sewage dealt with by the filter is not excessive, that is to say is not more than 250 gallons per effective yard per day of eight hours, with a rest of sixteen hours, without any sewage going on, an effluent is, as a rule, produced which contains considerably less than 0·1 part of organic ammonia per 100,000, absorbing less than one part of oxygen at 80° Fahr. in four hours, and containing one part of nitrogen as nitrates. Unfortunately, many of the filters constructed by this Company were constructed to deal with 600, 700, and even 1000 gallons of sewage per square yard, and where these artificial filters have been brought into discredit, it is by their being thus overworked.

The action of the nitrifying filter can perhaps be best understood by comparison with an analogous change which takes place in the fermentation of alcohol into vinegar through the action of the *mycoderma aceti*, and it is worth while to fully consider what the vinegar brewer does when he conducts his operations.

He allows a solution of alcohol to drip slowly over birch twigs in a current of air at a temperature of 77° Fahr. for a fortnight. During this time an organism known as the *mycoderma aceti*, which is seeded on the twigs, flourishes, and, in its growth, takes up oxygen from the air, and unites this with hydrogen from the alcohol, thus forming acetic acid and water. The chemical change which takes place may be represented as follows—

$$\begin{array}{ccccccc} \text{Alcohol} & + & \text{oxygen from the air} & = & \text{acetic acid} & + & \text{water} \\ C_2H_6O & + & O & = & C_2H_4O & + & H_2O \end{array}$$

I have said that the changes which take place in a sewage filter are analogous to this fermentation, and I have no doubt saltpetre could be produced from sewage, by treating it as the vinegar brewer does his alcohol, but the expense would be prohibitive.

The changes sewage undergoes are, however, more complex. First of all, albuminous matters, and such substances as the urea of the urine (which is the form in which the great bulk of the nitrogen leaves the human body), get converted, into carbonate of ammonia. This change, known as "bacteriolysis," results from the action of the *bacillus ureæ* and other organisms present in the sewage, and is complete by the time the sewage reaches the precipitation tanks.

The change which it is now desired to effect may be regarded, then, as the oxidation by means of nitrifying bacteria of a solution of carbonate of ammonia into the nitrate of some base, generally lime, and this action is known as nitrification.

This is an operation which has been carried on by the Chinese in the manufacture of saltpetre for thousands of years, and the factors necessary for its success are as follows:

1. A substance which will yield ammonia.

2. The presence of calcareous matter to neutralize the nitric acid when formed by the nitrifying organisms; for this reason (except in towns with hard waters) lime should form a constituent of the precipitant.

3. The presence of air in the pores of the filter.

4. A temperature as near 100° Fahr. as possible.

5. A certain amount of time must be allowed for the organisms to grow. On this account the quantity of the sewage applied should never exceed three gallons per square foot of filter per hour, and the filter should only be worked for eight to ten hours a day.

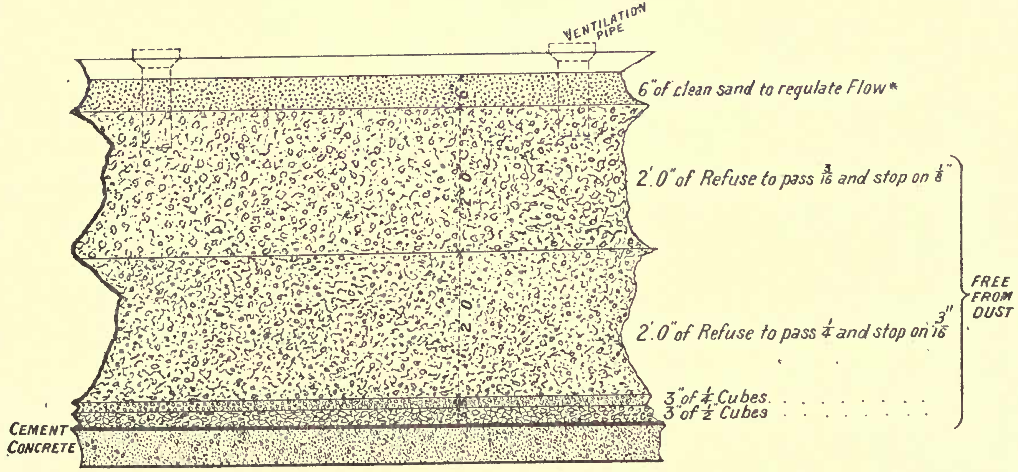
6. As the air in the pores of the filter is consumed, it must be renewed again. This is either done by applying the sewage intermittently, or, as suggested by Mr. Lowcock, by blowing a small quantity of air into the lower part of the filter continuously.

7. The success of the sewage filter will to a great extent depend upon the size of the particles of the sewage filter and its consequent porosity, and to some extent upon the mechanical texture of the material being sufficiently rough to retain the colonies of nitrifying organisms.

When there is a sufficient area of sandy gravel, all these conditions are supplied by nature, except the systematic renewal of the air. This can be arranged by adopting an automatic flushing tank, which will apply the sewage intermittently to the land, the air being drawn into its pores between the flushings ; where there is not sufficient fall for one of these contrivances to be adopted, great care must be exercised in frequently changing the areas irrigated.

It will be seen that these filters act chemically and biologically ; the dissolved organic matter does not pass out of the filter in the same condition that it enters it—namely, as albuminous matter—but as nitrates. With these coarse-grained artificial filters much more sewage can be passed through in the twenty-four hours than could be passed through land, but little purification would be effected if more than 200 or 300 gallons were filtered. This will be perfectly obvious when we bear in mind that, as has been pointed out, about half the weight of the nitrates produced consists of oxygen, and that therefore, to produce the nitrates, the nitrifying organisms must be freely supplied with oxygen by allowing the filter to empty, and thus cause the air to penetrate into all its interstices.

The necessity for adequately aërating filters was first scientifically worked out by the Massachusetts State Board of Health, who had an experimental station at Lawrence from 1889 to 1893.



SECTION THRO FILTER.

* The rate of Filtration should be such that the water falls in the Filter 6 to 8 inches in one Hour.

FIG. 12.—Diagram showing METHOD OF CONSTRUCTING ARTIFICIAL SEWAGE FILTER.

The experiments of the Board were made in a series of circular tanks—seventeen feet in diameter and six feet deep. The bottoms of the tanks were drained with ordinary horse-shoe land drains, and large gravel from one inch to two inches in size, covered over with a layer of pea gravel about one-eighth of an inch in size.

The more important experimental tanks were filled as follows—

Tank No. 1.

Five feet of clean coarse sand.

Tank No. 2.

Five feet of fine sand.

Tank No. 3.

Four feet of peat covered with one foot of the original top layer of peat.

Tank No. 4.

Five feet of river silt, very fine sand.

Tank No. 5.

Five feet of garden soil.

Tank No. 6.

Three feet eight inches of coarse and fine sand and fine gravel.

They also experimented with a number of other filters, such as three feet eight inches of coarse sand and fine gravel (same as No. 6), covered with ten inches of sandy loam, and six inches of soil; and three feet eight inches of coarse sand and fine gravel (same as No. 6), covered with eight inches of sandy loam, and eight inches of sandy gravel.

The area of the filters was, roughly speaking, $\frac{1}{200}$

of an acre, and they were used for six days in the week.

The following are the most instructive of the results obtained—

No. 1. **Coarse Sand.**—This filter had a total capacity of 12,300 gallons, and, when filled with water, was found to take up 3240 gallons. When drained away, however, only 2200 gallons of water could be run out, 1040 gallons remaining in the filter owing to capillary attraction; so that when the filter was drained dry it was charged with 2200 gallons of air.

By these experiments the importance of capillarity was first thoroughly brought home; and in the experiments with the fine river silt and garden soil, no nitrification occurred even when the quantity of sewage filtered was only about 7000 gallons to the acre per day. When we recognize the fact that the whole of the nitrification depends entirely upon getting the air in the interstices of the filter changed, the importance of constructing a filter of material of such a size that capillary attraction shall not prevent it from rapidly draining dry will be appreciated.

In filter No. 1, about 100,000 gallons of sewage to the acre were filtered in 24 hours, about 86 per cent. of the albuminoid ammonia being removed, and 89 per cent. of the bacteria.

No. 2. **Fine Sand.**—This filter was only able to deal with 40,000 gallons of sewage to the acre; but although the quantity of sewage that could be purified was less than half that in filter No. 1, it effected a higher degree of purification. The reduction of the albuminoid ammonia was as much as 97 per cent., and as many as 99·8 per cent. of the bacteria were removed.

No. 3. **Peat.**—Without going into detail with regard to tank No. 3, the peat tank, it is sufficient to say that, from the results obtained, the Massachusetts experimenters came to the conclusion that this material was "entirely worthless for the filtration of sewage."

No. 4. **River Silt.**—The results obtained by this filter are similar to those obtained by filter No. 2, the fine sand filter; only, as might be expected, as the material was of finer texture, the quantity of sewage that could be filtered was less. On the other hand, the purification effected was, in some respects, greater. Only 30,000 gallons of sewage per acre could be filtered in 24 hours, and 96 per cent. of albuminoid ammonia was removed, or a little less than in filter No. 2. The smaller chemical purification effected is probably due to the fact that there would be a great difficulty in getting the oxygen into the interstices of the finer filter; but, on the other hand, in this filter, as many as 99·9 per cent. of the bacteria in the sewage were removed.

No. 5. **Garden Soil.**—It was found that the quantity of sewage that could be purified with the garden-soil filter was still less, and the reports state that with a depth of five feet no purification by nitrification took place. Although it was probable that no bacteria came through, the organic matter in the effluent was, at the end of two years, nearly as great as in the sewage. This soil remained continually so nearly saturated that, when only 5000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce nitrification.

The following Tables show the changes which were effected by fine-gravel filters worked at the rate of 100,000 gallons per acre per day, the sewage being applied fourteen times a day for six days in the week. The air in the interstices of these filters was estimated at one-third their total capacity.

Fine Gravel Filters.—Parts per 100,000.

1889.		Ammonia.			Chlorine.	Nitrogen as	
		Free.	Albuminoid.	Sum of.		Nitrates.	Nitrites.
May 23	Sewage .	1·9919	0·6031	2·5950	5·16	0·0	0·0
to	Effluent.	0·0031	0·0375	0·0406	6·00	2·0700	0·0002
June 22.	Reduction in albuminoid ammonia 94 per cent.						
June 23	Sewage .	2·2500	0·7255	2·9755	7·46	0·0	0·0
to	Effluent.	0·0050	0·0354	0·0404	9·0104	2·2500	0·0004
July 22.	Reduction in albuminoid ammonia 95 per cent.						
Sept. 24	Sewage .	2·0559	0·6453	2·7012	5·55	0·0	0·0
to	Effluent.	0·0068	0·0325	0·0393	6·42	0·5700	0·0003
Oct. 24.	Reduction in albuminoid ammonia 95 per cent.						

The number of bacteria per cubic centimetre was reduced in the following proportion :—

June 23 to July 22.	In the sewage ...	1,813,500
	In the effluent ...	13,523
	Reduction per cent.	99·3
Sept. 24 to Oct. 24.	In the sewage ...	3,034,000
	In the effluent ...	11,592
	Reduction per cent.	99·6

The American experiments, however valuable, were only made with weak sewage, and upon a very small scale. They demonstrated clearly the necessity for making the supply of sewage intermittent, and showed a percentage of purification which had never been obtained before.

The London County Council, however, repeated the experiments in a modified way on a much larger scale. They constructed one filter of coke breeze (or rather what is technically known as "pan waste") an acre in extent. They also tried smaller filters of the following materials :—

1. Burnt ballast.
2. Lowestoft shingle, pea size.
3. Coke breeze.
4. Sand.
5. A filter containing a certain amount of polarite.

The London sewage was first of all precipitated in the ordinary way with lime water, and the tank effluent thus obtained was filtered.

The average results from the smaller filters are given* below :—

Description of filter.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average purification effected, as determined by oxygen absorbed.
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.	
					Per cent.
Burnt ballast ...	1·881	1·072	0 243	0·125	43·3
Pea ballast ...	1·881	0·880	0·257	0·142	52·3
Coke breeze ...	1·881	0·711	0·262	0·103	62·2
Sand	1·725	1·001	0·250	0·132	46·6
Proprietary filter	1·881	0 721	0·267	0·106	61·6

In the face of these results, a large filter, an acre in extent, was put down. This large filter was composed of three feet of coke breeze and three inches of gravel. After a number of preliminary experiments, the quantity of sewage filtered was gradually increased until as much as 1,000,000 gallons of the tank effluent were filtered per acre per day. As a matter of fact, the quantity filtered was $1\frac{1}{6}$ million gallons per day for six days, the filter resting from ten on Saturday till six on Monday morning. The filter was worked under the supervision of Mr. Dibdin, F.I.C., the late chemist to the London County Council, and the method of working it, which is original, was as follows :—

The outlet from the filter was closed, and the

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* The results obtained by the London County Council have been published as separate reports; they are also succinctly epitomized in "The Purification of Sewage and Water," by W. J. Dibdin, F.I.C,

sewage was allowed to run on to the filter until it became quite full, its surface being submerged; this generally took about two hours. The filter was then allowed to remain standing, without any more sewage going on, for just one hour, as Mr. Dibdin is of the opinion that the nutrifying organisms require a definite time in which to effect nitrification. After it had been standing for one hour, it was allowed to drain dry. This part of the process took about five hours, so that the whole of the process of filtration took eight hours.

The amount of nitrification effected as given by Dibdin is shown in the Table on next page.

In conclusion, it should be borne in mind that the coarse-grained filters which are worked intermittently effect the largest amount of oxidation or chemical purification. On the other hand, the finest grained sand filters, worked continuously, although effecting no chemical purification, arrest the largest quantity of bacteria.

The most perfect system of purification would consist of passing the sewage first of all through an intermittent filter of coarse coal to thoroughly oxidize the ammonia into nitrates, and then to filter the effluent continuously through fine sand or river silt to arrest the bacteria. Such a dual process is indicated for works above the intake of any water company.

Results of Experimental Filter of Coke Breeze of the London County Council.*

Date.	Gallons per acre per day.	Oxygen absorbed in four hours at 80° Fahr.			Albuminoid ammonia.			Nitrogen as nitrates. Grains per gallon.	
		Grains per gallon.		Percentage of purification.	Grains per gallon.		Percentage of purification.		
		Tank effluent.	Filtrate.		Tank effluent.	Filtrate.		Tank effluent.	Filtrate.
1894. April 7 to June 9 ...	500,000	4·096	0·856	79·3	0·416	0·095	77·2	0·1280	0·2378
August 3 to November 9 ...	600,000	3·608	0·730	79·6	0·396	0·113	71·4	0·0223	0·1414
November 16, 1894, to March 2, 1895	1,000,000	4·113	0·935	77·5	0·382	0·114	70·2	0·3956	0·6990
1895. April 8 to April 20	1,000,000	3·512	0·884	75·4	0·360	0·102	71·7	0·1431	0·7700

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* "Purification of Sewage and Water," W. J. Dibdin, p. 57.

CHAPTER VIII.

SPECIAL FORMS OF SEWAGE FILTERS.

Ducat's filter—Garfield's coal filter—Sewage distributors—The Lowcock filter—Comparative results with coke, breeze, coal, sand, and Lowcock's filter, Tipton and Buxton—Automatic arrangements for applying sewage intermittently.

Ducat's Filter.—A further improved method of filtering has been brought out by Colonel Ducat, late Inspector of the Local Government Board. The peculiarity of this filter is, that it is capable of filtering crude sewage. Its sides are constructed of ordinary drain pipes so placed that the outer ends are higher than the inner ones. At certain levels layers of drain pipes go through the whole of the filter. The sewage is caused to trickle *continuously* from carriers going over its surface. By this arrangement it is claimed that the air passes continually through the filter laterally, and that in consequence it will not require rest, and need not be worked intermittently.

The author had the opportunity of seeing this filter at work on September 3rd, 1897. The crude sewage going on yielded 0·72 part of albuminoid ammonia in 100,000, while the filter effluent contained 0·09 part of albuminoid ammonia, and as much as 2·5 parts of nitrogen as nitrates. The percentage of purification effected was 87·5. The quantity of sewage filtered per square yard of filter was 250 gallons per day of 24 hours.

It should be borne in mind that Colonel Ducat, at Hendon, is dealing with raw sewage which has not been precipitated; the depth of the filter, however, is eight feet. Whether better results still would be effected by constructing the filter of coal is a point which is worth experimenting upon. Another arrangement which Colonel Ducat has made is for the filter to be kept warm in the winter months by passing hot-air pipes through it, the air being heated by a slow combustion stove. In a paper read at the Glasgow Conference of the Bristol Institute of Public Health, in September, 1895, the author suggested the advisability of keeping all sewage filters warm by the circulation of hot-water pipes at a temperature of 90° Fahr.

Since the London County Council experiments were made, a considerable number of filter experiments have been carried out in Derbyshire and Staffordshire.

Coal Filters (Garfield's Patent).—Mr. Garfield, engineer of the Sewage Disposal Works, Wolverhampton, and Mr. E. W. T. Jones, County Analyst, Staffordshire, have made a large number of experiments with different filtering media, and they found that the most striking results could be obtained by filtering a tank effluent through coal. The reason why coal should give such excellent results is by no means settled, but there can be no doubt as to the high percentage of purification effected by this medium. The size of the material is a factor of the greatest importance. The authors of the coal-filtering process found that the best results are obtained with filters of a depth not greater than five feet. The bottom three inches of the filter is constructed of inch cubes covered with half-inch cubes for another three inches, this latter being covered with two feet of coal (*free from dust*) which will pass through a $\frac{3}{8}$-inch screen, but stop upon a $\frac{1}{4}$-inch screen, and upon this is a layer of two feet of coal washed *free from dust*, of a size that will go through a $\frac{1}{4}$-inch screen, but stop on $\frac{1}{8}$-inch screen. The top layer of all is composed of coal containing dust which will go through a $\frac{1}{8}$-inch screen. The object of this layer is to distribute the sewage evenly all over the surface of the filter (see Fig. 12).

Mr. Garfield, like Colonel Ducat, works his filters on an entirely different plan from Mr. Dibdin. Instead of closing the outlet of the filter so as to fill it, he distributes the sewage over the surface of the filter by means of iron troughs or pipes which constantly overflow, or by means of a distributor. This distributor will work with a head of three inches and is also suitable for a head of many feet.

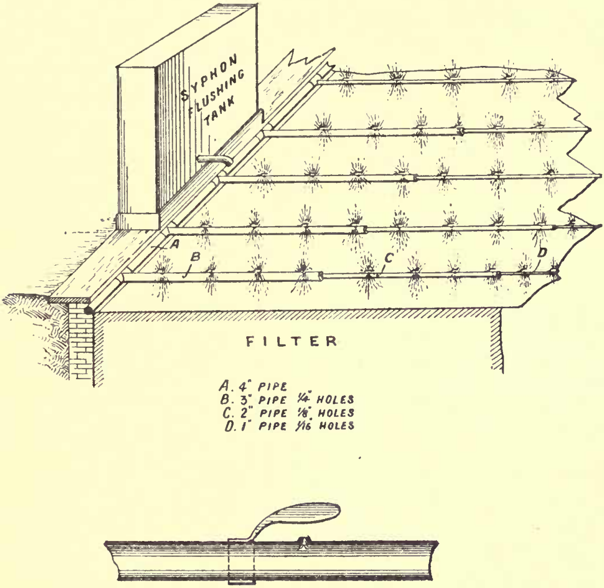
It consists of small galvanized tubes (say ¾-inch in diameter) resting on the surface of the filter and placed say three feet apart. These tubes are perforated with small holes, the size of which depends on the head of water and quantity to be delivered. These holes are also three feet apart. The whole series of the tubes are connected in the middle of their length by levers to a rod, which can be moved by hand or otherwise, through an angle of 45°, thus the jet is first thrown on one side of the tube and then on the other. The jets on one tube being half way between the jets on the other, a good and even distribution is obtained.

It will be seen that, in the process of filtering sewage, it is a matter of the greatest importance to have the sewage distributed uniformly over the surface of the filters. A glazed sanitary ware sewage distributor has been brought out by Messrs. Wragg of Swadlincote.

A further improvement is the sewage distributor of Mr. Corbett, the Borough Engineer of Salford. This consists of an arrangement for varying the quantity of sewage from time to time by an automatic flushing syphon, the sewage itself being distributed over the surface of the filter by means of iron pipes three or four feet apart, and having ⅛-inch to ¼-inch holes every three or four feet in their length. Two inches above each hole is an iron plate upon which the sewage impinges, and is thrown in a circle all round.

As the head in the flushing tank diminishes the radius of the circle narrows, and in this way every part of the filter is alternately sprinkled. See Fig. 13.

Besides the coal filter, which up to the present time has given the best results ever obtained, the Lowcock filter has recently been tried in Staffordshire.



ENLARGED SECTION.

FIG. 13.—AUTOMATIC SEWAGE DISTRIBUTOR.

The Lowcock Sewage Filter.—In this most striking innovation in sewage filtering, the principle is adopted of artificially aërating the filters by means of a small blower, and thus increasing their efficiency by supplying the air needed for the sustenance of bacterial action. It is obvious that if this could be accomplished, instead of having filter beds in triplicate, to be used in turn, a filter bed could be used continuously, and a great saving of money and space could thereby be effected. The idea seems to have struck Mr. Lowcock, of Birmingham, and Colonel Waring, the well-known American engineer, about the same time. The two filters, however, have this difference—Mr. Lowcock introduces his air at the middle and blows it out with the effluent at the bottom, while Colonel Waring aërates his filters upwards.

The Lowcock filter (see Fig. 14) consists of three inches of sand resting on nine inches of pea breeze; this in turn rests on twelve inches of bean-sized pebbles, in the middle of which are a number of perforated pipes connected with a blower, which supplies a slow continuous stream of air evenly distributed all over the filter. The layers of the filter above the air are more closely packed than below, so that the sewage and air pass as frothy films downwards over three feet of coke breeze, or other suitable material, to the large open outlet at the bottom.

The pressure of the air necessary to accomplish this is not more than equal to a column of water three or four inches in height. It is obvious that

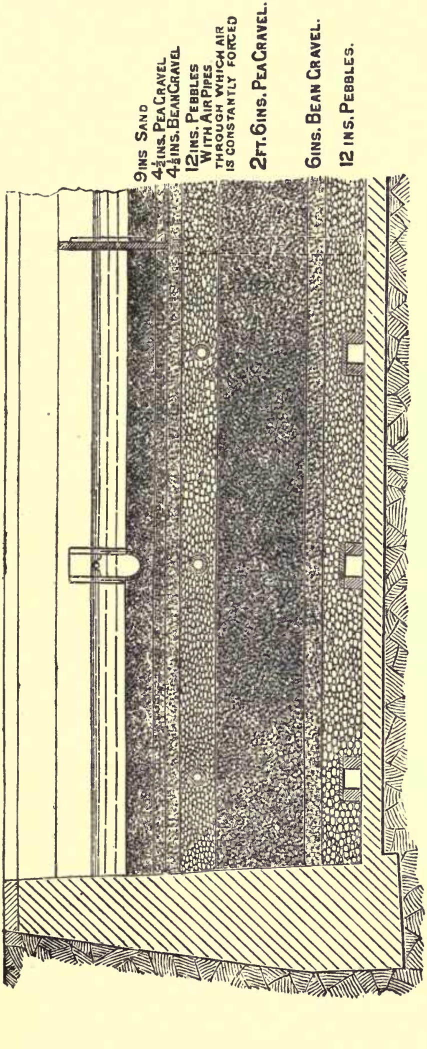


FIG. 14.—Section through LOWCOCK'S FILTER.

if there is nine inches of water on the top of the filter the air will not pass up; but I believe the filters are now prepared by selecting the material of gradually increasing size from above downwards, so that, even when no water is in the filter, the air passes out at the bottom. The advantage of this is that it leaves the top of the filter undisturbed to intercept any matters left in suspension from the precipitating tanks and clarifiers. The work of the filter can be increased where there is fall to any depth, more air being supplied at different levels. The result is, that oxidation and nitrification proceed continuously and rapidly.

Colonel Waring was able, at Newport, U.S.A., to effect a purification of 92·5 per cent.; while Mr. Lowcock, dealing with the Wolverhampton sewage, which is extremely difficult to treat, reduces the albuminoid ammonia from 80 to 90 per cent.

Comparative Trials.—The coal, coke breeze, and the Lowcock filters have been tried at Tipton with the following results, for the report of which the author is indebted to Dr. George Reid, the County Medical Officer of Staffordshire :—

	Sample.	Number of samples analyzed.	Parts per 100,000.								Percentage purification.	
			Solids.			Chlorine.	Free ammonia.	Organic ammonia.	Oxygen absorbed in 4 hrs. at 80° Fahr.	Nitric nitrogen.	On organic ammonia basis.	On oxygen absorbed basis.
			In solution.	In suspension.	Total.							
	Tank effluent ...	13	82·7	1·6	84·3	10·2	1·25	0·23	0·77	Nil		
	Old large sand filter	15	76·6	1·5	78·1	10·8	1·19	0·14	0·53	0·09	38·2	31·2
Experimental	Coke breeze ...	10	84·0	0·9	84·9	10·0	0·90	0·16	0·58	0·38	33·2	29·0
	Lowcock's	8	80·7	1·4	82·1	10·0	0·27	0·05	0·22	0·74	75·7	68·5
	Garfield's coal ..	8	91·4	0·3	91·7	10·6	0·19	0·04	0·20	0·81	80 6	70·8

The following are some results obtained with coal, destructor breeze, and coke breeze filters at Buxton :—

	Parts per 100,000.			
	Tank Effluent.		Filtered Effluent.	
	Organic ammonia.	Nitrogen as nitrates.	Organic ammonia.	Nitrogen as nitrates.
Destructor breeze filter	0·23	Nil	0·10	0·10
Coke breeze filter ...	0·23	Nil	0·11	0·09
Coal filter	0·23	Nil	0·05	0·42

In addition to being tried at Buxton and Tipton, coal filters have been tried at Lichfield, Chesterfield, and Kimberley with equally striking results.

Effluents, such as those from the coal filters at Tipton and Buxton, containing a large quantity of nitrates and little organic ammonia, are chemically practically perfect.

Another improvement which ought to be mentioned with regard to the question of sewage filtration, is the application of the sewage intermittently to the filters by means of automatic flushing tanks. Mr. C. J. Lomax has constructed polarite filters at Failsworth upon this plan.

Instead of having filters in triplicate, using each filter for eight or twelve hours, and then letting it rest for twelve or sixteen hours, each filter is supplied with two automatic flushing syphons, which discharge once every twenty minutes. The tank effluent is allowed to accumulate in a special reservoir for twenty minutes, the syphon then comes into action, and in a minute or two spreads the accumulated clarified sewage over the area of the filter bed, in five minutes the sewage disappears from the surface of the filter and draws air into its interstices. This air remains in contact with the thin films of organic matter left on the surface of the polarite for fifteen minutes, when the syphon again discharges. By placing one's hand at the effluent outlet pipe, just after the syphon has discharged, it is quite easy to feel the air being displaced—in fact, the current is sufficient to blow a match out if the outlet valve is half closed. No analyses are available to show the quantity of oxygen from the air taken up by the sewage, but if the quantity of the sewage is only kept low enough—say, not exceeding 250 gallons per day, per square yard—I believe 80 or 90 per cent. of purification would be effected.

From the number of experiments and actual demonstrations which have been carried out, it has been shown that any degree of purification desired can be effected with sewage filters, by diminishing the quantity of sewage to be filtered per square yard.

A method of making filters work automatically on the Dibdin system is the alternating gear devised by Mr. Cameron, of Exeter. In this arrangement, the effluent from the filter gradually fills a chamber off the effluent drain until the filter is completely waterlogged; the water rising in this chamber actuates a float which releases a valve at the outlet of the filter, and at the same time turns the tank effluent on to another filter. The author has thoroughly investigated this ingenious method of working the filters, and it can be thoroughly relied upon.

More recently still, the simpler method has been adopted of putting an automatic flushing syphon in a chamber in connection with the effluent drain. The effluent from the filter gradually fills this chamber until the filter is waterlogged, it then syphons the filtrate out of the filter very rapidly. This arrangement in practice was found not to work unless ventilating pipes are passed freely through the top part of the filter.

CHAPTER IX.

THE NEW DEPARTURE "BACTERIOLYSIS."

Scott Moncrieff's and Adeney's experiments—The Exeter septic process of Cameron—Results obtained at Exeter—Gases resulting from the septic process.

During the last few years attempts have been made by Messrs. Scott Moncrieff and Donald Cameron, of Exeter, to avoid the necessity for precipitation by causing the organic solid matter in suspension in the sewage to become liquefied by means of certain bacteria.

It is well known that many bacteria have the power of liquefying solid albuminous matter; in fact, one of the ordinary methods of distinguishing different species of bacteria is to ascertain their action upon such substances as gelatine, and as many as 196 varieties out of 440 well-known bacteria have this property of liquefying gelatine.

Scott Moncrieff liquefies the organic matter by straining the sewage through shallow channels filled with flints upon the surface of which the liquefying organisms grow.

Mr. Adeney, of Dublin—to whom we owe the word "bacteriolysis"—has suggested that the purification also of sewage could be effected by the action of micro-organisms by adding a sufficient quantity of nitrate of soda to the sewage.

Dr. Sims Woodhead found that in 1 c.c. of Exeter crude sewage there were one million organisms which were anaerobic, or did not grow in the presence of air, and 5½ million organisms which were aerobic, or did live in the presence of air. Of the one million anaerobic, 300,000 were found to be liquefying organisms; and of the 5½ millions aerobic, 500,000 were also found to be liquefying: so that the proportion of liquefying organisms was found to be greater among the anaerobic than among the aerobic.

The rapidity with which the various bacteria liquefy the solid organic matter varies considerably, and it is claimed by Mr. Cameron that those bacteria which live in the absence of air are the most active liquefying organisms.

The Exeter septic process of purification consists of conducting the sewage into large closed tanks capable of holding a day's sewage. The tanks are covered with concrete arches carried by brick piers and levelled over with soil; they are designed to promote the growth of the liquefying organisms present in the sewage, by whose action the organic solids are naturally broken down into simpler substances which can be dealt with by filtration. The flow through the tanks is uniform and continuous, the inlet and outlet being submerged so as to minimize the disturbance of the contents of the tank by the incoming and outgoing streams, and to prevent the admission of air or the exit of gases into the sewers. It is claimed that practically the whole of the organic matter in suspension is by this means rendered liquid.

In the experimental tanks at Exeter, it was found that during the first few months there was an increase in the depth of the deposit in the tank at the rate of an inch per month; but after this, when the sludge has accumulated to a certain extent, the bacteria practically eat it away as fast as it is formed.

In addition to the layer of the sludge at the bottom of the tank, a scum three or four inches in thickness also forms at the top, and flakes of organic matter fall from the surface scum to the bottom of the tank. At the bottom of the tank, therefore, decomposition takes place, and bubbles of gas are carried from this fermenting mass out at the top of the tank, and, in this way, millions of bacteria are continually falling with the organic matter from the scum to the bottom of the tank. Bubbles of gas keep ascending to the top, and carry with them other colonies of bacteria. The whole of the mass in the tank is thus constantly interchanging, and the liquefying bacteria are thus brought in contact with the whole of the organic matter in suspension.

Of course it is quite impossible for the bacteria to dissolve the road detritus, and reference to Table I. shows that, while the mineral matter in the American sewage was about 5 parts per 100,000, and in the Exeter sewage 10 parts, that in a mining district, like Alfreton—where the quantity of water used is less than 10 gallons per head per day, and there are no water-closets—the mineral matter in suspension is 32·5 parts per 100,000. This suspended matter will have to be got rid of, either by simple subsidence before the sewage enters the septic tank, or else be precipitated in an ordinary Dortmund tank. At Exeter, it is proposed to let this mineral matter subside in three grit chambers, each fifteen feet square, and fifteen feet deep.

After the sewage has passed through the septic tank, it is subsequently filtered through biological nitrifying filters, just as the tank effluent from a precipitating tank is filtered.

At first sight it would appear that, by rendering the solid organic matter in suspension soluble, the amount of organic matter to be nitrified would be increased; and because the sewage would be rendered stronger the difficulty of the problem would be increased.

At Exeter, however, there is no doubt that this is not so; indeed, the total organic matter is actually reduced by the process which takes place in the septic tank.

Mr. Perkins, the Public Analyst of Exeter, found that the average effluent from the septic tank collected throughout the 24 hours yielded 0·66 part of albuminoid ammonia per 100,000, while the raw sewage contained 1·2 parts, the purification effected being nearly 50 per cent.

Dr. Rideal found the albuminoid ammonia was reduced from 1·4 to 0·64 part per 100,000, or a purification of 55 per cent.

The author collected two samples at the same time in dry weather, when the crude sewage was found to contain 0·48 part of albuminoid ammonia per 100,000, and the septic tank effluent contained 0·25 part.

The chlorine at the same time showed that the raw sewage and effluent were similar, while the albuminoid ammonia showed a reduction of nearly 50 per cent.

Messrs. Dibdin and Thudichum found that a purification of 17·5 per cent. was effected in the septic tank.

The actual figures obtained by Mr. Dibdin were the average of twelve samples, the crude sewage yielding 0·212 part of albuminoid ammonia per 100,000, and the tank effluent 0·175 part. The crude sewage is of an exceptionally weak character.

Dr. Dupre found the reduction effected in the organic nitrogen as 27·7 per cent.

The question immediately arises, What becomes of the organic matter in the septic tank? The answer to this is, that it leaves the tank in the form of various gases.

Dr. Rideal gives the following two analyses of gases formed in the septic tank:—

	Per cent. by volume.	
Carbonic acid gas, CO_2 ...	0·3 ...	0·6
Marsh gas (methane), CH_4 ...	20·3 ...	24·4
Hydrogen, H	18·2 ...	36·4
Nitrogen, N	61·2 ...	38·6
	100·0	100 0

The gas which is formed is inflammable, and can be burnt through a Bunsen burner; or, in a scheme carried out on a large scale, it could be driven through a water-trap, so as to prevent any risk of explosion, and be burnt under steam boilers, or the heat might be utilized to keep the nitrifying filters warm. In addition to the gases which are driven off from the tank, a considerable amount of carbonic acid passes away dissolved in the tank effluent.

The Table on next page gives the analyses of the raw sewage and tank effluent collected by the writer at 4.45 p.m., on January 3rd, 1898.

It will be noticed that the tank effluent contained a small trace of nitrites. Dr. Rideal also found nitrates in the tank effluent, while Dr. Dupre found that the tank effluent contained from 0·05 to 0·06 part per 100,000 of nitrites as nitric and nitrous acid. This fact is of great importance, because the oxygen in the nitrites certainly did not enter the sewage in the tank, as it is closed as perfectly as it practically can be. It therefore shows that there is in the Exeter sewage a supply of oxygen sufficient to commence the process of nitrification. This condition, which is peculiar and most exceptional in the sewage, is one that is particularly favourable to this process; and wherever similar circumstances exist, the Exeter septic process may be considered as a suitable substitute for precipitation, and the annual cost of chemicals, and the difficulty of dealing with sludge be thereby avoided.

ANALYSES OF RAW SEWAGE AND TANK EFFLUENT
(January 3, 1898).

	PARTS PER 100,000.					
	Total solids.	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrogen as nitrates and nitrites.	Chlorine.
Sewage, 4.45 p.m. ...	63·0	1·60	0·48	Nil	Nil	5·6
Septic tank effluent, 4.40 p.m.	65·6	4·00	0·25	trace	0·13	6·3
Filtrate, filters 1 and 3, three hours after discharge	65 2	0·185	0·09	Nil	2·00	5·6
Filtrate, filter 4, five minutes after discharge	63 5	0·20	0·09	Nil	2·00	5·5

CHAPTER X.

CONCLUSION.

What process of purification to adopt—When a sewage farm—When precipitation and land—When precipitation and artificial filtration—Indications for a septic process.

The question with which every Sanitary Authority is brought face to face is the very concrete one of "What process shall we adopt to purify our sewage?"

Before this question can be answered, certain definite knowledge must be obtained as to the nature of the sewage to be treated. Under this heading, information is required as to the nature of the manufacturing wastes turned into the sewage; whether there is a public water supply; the quantity and quality of the water of the district; the quantity of sewage per head per day. If the water supply is obtained from surface wells, the quantity of sewage will probably not be more than ten gallons per head per day. With regard to the water, it should be ascertained whether it is hard or soft, and whether it contains a large quantity of sulphates.

Another important point upon which information must be obtained is, whether the sewers of the district have a good fall so that the sewage will reach the works comparatively fresh, or whether the sewers are flat and the sewage will be in an advanced state of decomposition by the time it reaches the sewage disposal works.

Then another material point will be to ascertain whether much surface water enters the sewers, and an average day's sample of the sewage should be collected for experimental treatment.

Nothing more than broad generalizations can be laid down without definite instances to deal with.

In the first place, let us suppose that we have ordinary domestic sewage to purify, one not containing any manufacturers' wastes. The first investigation that should be made is as to whether there is a sufficient area of good sandy or gravelly soil which can be commanded by gravitation. In carrying out this investigation, great assistance will be obtained by carefully studying the geological maps of the district, particularly if published on a scale of six inches to the mile.

Speaking generally, if the locality is on the boulder or other clay, the new red marl, the coal measures, Yoredale and limestone shales, the mountain limestone, and the pre-Cambrian rocks, the land may be pronounced as not suitable for sewage farm purposes. If, on the other hand, the formation is blown sand, drift, or other gravel, flint and chalk, bunter sandstone, old red sandstone, or possibly the millstone grit, a sewage farm may be advocated.

The next step will be to have trial holes dug to a depth of six feet; too many of the holes cannot be dug, as it is frequently found that patches of sand or gravel, particularly if by the side of a river, do not extend over such large areas as they apparently seem to.

What will be found very useful in carrying out these investigations is a small boring tool five or six feet long, and half-an-inch to three-quarters of an inch in diameter. With this instrument, the nature of the soil and subsoil may be ascertained, without obtaining leave to dig trial holes; and in the course of a couple of hours, with the assistance of a strong man, ten or more trial holes may be made.

Whatever process of purification is adopted, road detritus must be allowed to settle in detritus tanks, and gross suspended matters must be separated by screening the sewage through a half-inch screen. The best screening arrangement, and the simplest, is the cage screen in use at Buxton, illustrated in Fig. 7.

Having come to the conclusion that a sufficient area of sandy or gravelly soil is available, and that the land can be obtained for not more than £150 per acre, a sewage farm may be decided upon. The question will then arise as to whether it will be necessary to precipitate. The answer to this question will depend very largely upon the freshness and nature of the sewage. If it contains a lot of suspended matter, and is quite fresh, the sewers having good gradients, it is desirable that at least a rough kind of precipitating tank should be constructed. The tank effluent need not be of that purity that it is necessary to attain where biological filters alone are contemplated. If the sewage is stale by the time it reaches the disposal works, instead of a precipitating tank, a large settling tank and a rough strainer of coke breeze may be used. In any case it will always be found desirable to have laid out on the sewage farm a small biological intermittent filter, so that when the crops do not require the sewage it can be turned upon the biological filters, and the other arrangements described in Chapter V. should be carried out.

Where the land of the district is suitable for the purification of the sewage, but the price is more than £150 per acre, it will be found desirable to take a smaller area and adopt precipitation.

If the sewage is domestic and weak, either from there being a very large water supply, or because a large quantity of subsoil water finds its way into the sewers, and the water of the district is soft and does not contain many sulphates, such a method as the septic tank process may be indicated.

Where, however, there is not suitable land, or the sewage is not exceptionally weak, the process will have to be one of precipitation and filtration through biological filters.

With regard to precipitation, the best results will be obtained in the Dortmund tank. As to the chemicals which should be used, this will depend entirely upon the chemical nature of the sewage to be treated, and is a matter for definite experimentation in the actual tanks themselves after the construction of the outfall works.

When, however, the sewage contains manufacturing wastes, in almost every case precipitation will have to be adopted—the particular form of precipitant to be used varying with the nature of the manufacturing processes carried on in the district. As has been pointed out in the chapter on Precipitation, in some few cases, such as where there is a large proportion of brewery waste or tannery waste in the sewage, it will be necessary for the sewage to undergo special modifications of the process of purification.

First of all, dealing with manufacturers' wastes, all solid matters in suspension should be kept out of the sewers, and the wastes should be admitted to the sewers *continuously* throughout each working day. Under various circumstances it may be necessary to pass the sewage through a septic tank, and thus remove a large proportion of the organic matter by fermentation; and under some circumstances it must be remembered that the effluent from the septic tank will practically be a solution of sulphuretted hydrogen in sewage, and it will be necessary to subsequently precipitate with lime, or copperas, or a mixture of both, so as to prevent nuisance. After this, the tank effluent will have to be intermittently filtered through biological filters.

Again, under special circumstances it may be necessary to precipitate first, and then pass the sewage through a septic tank; and, in the third place, through biological filters. But these are only special cases, where a considerable amount of manufacturers' wastes, containing a quantity of organic matter, are admitted into the sewers.

Finally, for works above the intakes of a water company, after the sewage has been chemically purified by intermittent filtration, it is desirable that it should be bacteriologically purified by filtration through shallow filters of sand or fine silt.

In any case, before the engineer prepares his plans of construction, the scientific principles upon which the sewage is to be purified should be settled in consultation with a chemist and bacteriologist who has had special experience in dealing with this question. When our Local Authorities deal with this question in the manner advocated, we shall hear of fewer instances of failure and consequent disappointment.

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THE END.

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