Sewage Disposal.

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by

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During the greater part of the present century the problem of sewage disposal has been gradually becoming more and more urgent. Of course it existed long before the beginning of the century, and in some cases was even partially solved, for example, the irrigation of Craigentinny meadows in Edinburgh. In all probability that was resorted to more with a view to the benefit of the meadows and their fertility than to the purification of the sewage. It was only at the beginning of this century that the evils and dangers of neglecting this sanitary precaution came to be understood and recognised.

The necessity for safely disposing of sewage must have begun shortly after men began to congregate in fixed places of residence. In the case of nomadic tribes the problem would not arise, as

they, like micro-organisms working under favourable conditions, were "free to move away from their own poisonous products." Nature unaided could easily dispose of their sewage, so long as she was not interfered with. As the villages grew into towns and became more populous, there would be the more sewage to dispose of: it would be further added to by the establishment of factories of one kind and another, which discharged large volumes of refuse. So long as these villages and towns drew their water supply from streams, the evil effects of their own accumulations of refuse would not be felt in their fulness. The air would be polluted and probably injure the general health of the community, but would not lead to any great prevalence of specific disease. If, however, the town grew away from the stream, or was originally placed at some distance from it, so that the water-supply had to be provided from wells, the results were disastrous from the inevitable pollution of the drinking water. To remedy this state of matters supplies of water were introduced from a distance

thereby increasing the total volume of the sewage very greatly, to remove which it became necessary to construct systems of sewers. These sewers were naturally made to discharge into the nearest water-course. The sewage, so far as the community producing it was concerned, was thus effectually disposed of, but other communities living farther down the stream, who in all probability drew their water-supply from ~~the~~ it, now got the full benefit of the pollution. As these communities increased in size and number, the evil would increase, until the stream is ultimately converted into an open sewer containing neither animal nor vegetable life and pollut-ing the air all round.

Thus is produced a great nuisance, not perhaps so dangerous as the old cesspits whose removal has helped to increase it, but still calling urgent-ly for abatement.

Now, during this century many plans have been tried with a view to the removal of this class of nuisance, and the result of the experience gained is that we know that in any given

case the evil may either be easily remedied, or it may be a matter of the greatest difficulty, amounting in some cases, with our present means, almost to an impossibility. We may be able to attain our object by any one of the processes to be hereafter considered, or we may fail with nearly all of them. Why should there be this difference? The cause of the difference lies in the situation and surroundings of the communities producing the sewage. We must consider these, and then the changes it is necessary to bring about in sewage, and to what state it is necessary to reduce it, in order that it may no longer give rise to this nuisance.

The effect produced on a river or stream by the discharge into it of crude sewage (or imperfectly purified sewage) depends upon the following conditions:—

1. The quantity of the sewage.
2. The size of the stream.
3. The rate of flow of the stream
4. The degree of purity of the stream
5. The amount of plant-life in it

6. The uses to which the stream is put farther down its course.

If the quantity of sewage is small compared to the volume of the stream, if the latter runs fairly rapidly, if it is so far unpolluted, and if the waters of the stream are not used for drinking purposes lower down, this discharge (especially of domestic sewage) may not give rise to any very serious nuisance. Indeed it is certain that under these conditions a river, if it have only sufficient length of flow, will gradually rid itself of liquid impurities but not of solid. What the length of flow and lapse of time necessary for such purification are, cannot be accurately determined; they must vary ~~within~~ very widely with the conditions. The important point is, that this natural purification cannot and ought not to be solely relied on for the disposal of any sewage no matter how small in amount, but at the same time it may make a considerable difference when it comes to be a question of success or failure of a scheme for the purification of the sewage.

If, on the other hand, the volume of sewage is large, that of the stream small, if the latter has already been polluted, and if it runs sluggishly, the result cannot be otherwise than the creation of a very great nuisance. These conditions form a very severe test for the most efficient system of sew-age purification.

Between these two extremes there must be endless variations, and this it is which makes the fixing of a standard for the purity of an effluent, which shall be admissible to a stream, so difficult. In fact it is evident that no one standard can be applicable to all cases. A degree of purity necessary for a large effluent flowing into a small stream, which must be kept very pure for one reason or another, may only be attainable at a quite unreasonable expense in the case of a small effluent discharging into a large previously unpolluted stream whose waters are not subsequently used for domestic purposes.

The Commissioners appointed in 1868 to enquire into the best means of pre-

venting the pollution of rivers came to the conclusion after four years investigation that a fixed chemical standard should be set up. They recommended that the following should be deemed polluting and inadmissible into any stream :—

"a. Any liquid containing in suspension more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid

"b. Any liquid containing in solution more than two parts by weight of organic carbon, or 0.3 part by weight of organic nitrogen in 100,000 parts by weight.

"c. Any liquid which shall exhibit by daylight a distinct colour when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel

"d. Any liquid which contains in solution in 100,000 parts by weight more than 2 parts by weight of any metal except Calcium, Magnesium, Potassium, and Sodium.

"e. Any liquid which contains in 100,000 parts by weight, whether in solution

"or suspension, in chemical combination, or otherwise, more than 0.05 part by weight of metallic arsenic.

"f. Any liquid which after acidification with sulphuric acid contains in 100.000 parts by weight, more than 1 part by weight of free chlorine.

"g. Any liquid which contains in 100,000 parts by weight more than one part by weight of sulphur in the condition either of sulphuretted hydrogen or of a soluble sulphuret.

"h. Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1000 parts by weight of distilled water

"i Any liquid possessing an alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

"k. Any liquid exhibiting a film of petroleum or hydrocarbon oil upon its surface, or containing in suspension in 100,000 parts more than 0.05 part of such oil"

This standard was intended more particularly to be applied to effluents from

manufactories. It has however never been adopted, nor has any other. It is questionable if any fixed chemical standard could be made to suit all cases.

However desirable it may be, it is for the present impossible to return our water-supply to the river in as pure a state as it is brought into the towns: and the success or failure of any scheme for its purification prior to that return cannot be measured by the degree of its divergence in chemical analysis from such a standard of purity. For after joining a stream, if the scheme is successful, the effluent goes on improving during its flow, until it is finally restored to its original purity. If the scheme is unsuccessful on the other hand, it may deteriorate, putrefy and become very offensive. Yet if we were to take the two effluents, analyse them chemically, before they had joined the river, it is quite possible that the latter might appear the better of the two. The difference in their subsequent behaviour may be due to any one or more of several reasons, some of which we

have already looked at, and others, such as the condition of the constituents of the effluent, which we have yet to consider. For these reasons then it would seem to be useless to fix a chemical standard even for a given set of circumstances, not to mention for all and every case. Legislation on the subject should regard the effects produced by the effluent; if no nuisance is caused, then its purity is sufficient; if it is, then further means of purification are necessary. If the sewage is properly purified, the stream into which it is discharged should

1. Have no deposit in its bed.
2. Not be discoloured to any extent
3. Should be able to support fish life.

While we cannot draw a hard and fast line by chemical analysis, it may give us a good deal of information as to the effect of measures taken with a view to the purification of sewage. It is however impossible to judge of the effect of any particular system of purification from an analysis of the effluent alone. It is necessary to have a sample of the raw sewage taken at, as nearly as possible, the time that the

sample of effluent analysed would be entering the works. It is not a very easy matter to do this, but it may be accomplished by taking a large number of samples and averaging them. For instance, suppose the sewage takes 24 hours to pass through the works, then by taking hourly samples of the entering sewage for 24 hours, we shall have material which can be properly compared with hourly samples of the effluent taken during the next 24 hours. The result can then be stated as percentage purification, by taking some organic constituent as an index.

Composition of Sewage.

The composition of sewage is very complex and probably no two sewages are identical. Considering sewage with a view to its purification we may look upon it as water containing

1. matters in suspension
2. organic matter in solution
3. inorganic matter in solution
4. micro-organisms

The precise composition of the sewage

of any given community is influenced by the following:-

1. Whether the sewage is purely domestic, or is mixed with factory refuse.

2. Whether human excreta are largely kept out by some dry system of closet.

3. Whether rainfall is admitted to the sewers, and to what extent.

4. The density of the population, or in other words the habits of the people.

5. The hour of the day.

The first of those influences makes a very great difference in the composition of the sewage. What the difference is depends of course on the nature of the industry carried on.

The second, contrary to what would at first sight appear probable, makes comparatively little difference to the composition or offensiveness of the sewage. The sewage from a water closet town is not found to be more difficult to treat and purify than that from a town which removes its excreta by some dry method.

The third condition is very important, both as regards the construction of sewers, and also as regards the accommodation provided at any works for the disposal

of the sewage. If rain is admitted to the sewers, it means that both they and the disposal works must at times stand very sudden and great accessions to the volume of liquid usually dealt with. The difficulty may be overcome to a great extent by providing storm overflows at suitable points for the relief of the sewers and works. These overflows enable some of the sewage to escape treatment. If the sewers be well constructed no great harm may result, since the circumstances which lead to the overflow being used, ensure that the sewage is well diluted. Should however the sewers be imperfectly constructed, the heavy volume of liquid stirs up deposits which may have formed and the discharge from the overflow may be very foul indeed. These storm overflows may be trusted to, if the town is near the sea, or near a river whose waters are not used for domestic purposes lower down. Far better that what is known as the separate system should be adopted, i.e. one set of drains for sewage, another for rain. The sewage delivered at the works for

disposal will be more constant in quantity and in quality, and therefore will be much more easily dealt with. The objection has been raised to the separate system, that the scouring effect of the rain-water is lost to the sewage drains: the answer is that sewers should not depend on rain for their flushing, besides, the flushing by rain is absent when it is most required, namely, in dry, hot weather.

The fourth and fifth conditions influence both the quantity and the strength of sewage.

If, then, we wish to avoid unnecessary difficulty in the purification of sewage, we must see that manufacturers' refuse is excluded, or treated separately before admission to the drains, and that a separate system of drains is provided for as much of the rain-water as possible.

To purify sewage it is necessary to remove, as far as possible,

1. The suspended matters
2. The colour
3. The matter in solution, especially the organic. What cannot ~~the~~ be removed

must be left in as favourable a state as possible for its conversion into harmless inorganic compounds or elements. As has been stated before, the attainment or otherwise, of this last object can only be determined by observing the behaviour of the effluent after its discharge.

4. The Micro-organisms. It is one of the principal objects of sewage treatment, from a public health point of view, to get rid of all pathogenic organisms. What methods offer the greatest certainty of their destruction, we shall have to consider, but the means employed must of course not interfere with subsequent steps in the purification of the sewage. Several processes have been recommended, because they sterilised the sewage, destroyed all microbic life in it, possibly not an unmixed advantage.

We must now consider shortly the various methods employed with a view to purifying sewage. They may be classified as

1. Mechanical
2. Chemical
3. Electrical
4. Bacteriological

Mechanical Processes

These may be divided into (1.) Straining, (2.) Subsidence, and (3.) Filtration.

Straining — The straining of sewage is of course only capable of removing the grosser suspended matters. It is however a very essential preliminary to many of the processes which I shall have to describe. It may be accomplished in a variety of ways: — (1.) By some stationary form of screen, for example, a simple grating, or by passing the sewage through a cell formed by two gratings, the interval between them being filled with coke or some like material; (2) By means of rotary screens which remove the solids from the stream of sewage, and tip them into receptacles for the purpose

Subsidence, unaided by any addition to the sewage, is not a practicable method of dealing with sewage. To ensure any appreciable amount of subsidence the sewage requires to be brought almost to absolute rest, and to remain in that state for such a length of time that there is ample opportunity for ordinary putrefaction to advance to such a degree that a nuisance is created, and the last state of that

sewage is worse than the first. If, then, subsidence is to be aimed at, something must be added to the sewage to hasten it, and this brings the process into the chemical group.

Filtration. Neither is mechanical filtration an available means of treating sewage. Why? Because of the large quantities of solid putrescible matter left on the filter. These, as in the case of subsidence, get time to putrefy, and the products are added to the fresh sewage poured on the filter with disastrous results. Besides, the accumulation of these solids soon chokes the filter, the material of which therefore requires such frequent removal and renewal, that the process is out of the question. We shall afterwards see that what is called "artificial filtration" of sewage is not to any extent mechanical filtration at all; in fact if the mechanical action exceeds certain limits, it interferes gravely with the success of the process, and that for the reasons stated above. If any process leaves a loop-hole for putrefaction to step in, unless precautions are taken for its regulation and control, that process is doomed.

Chemical Processes

Before proceeding to describe the various, or at least the chief, chemical processes which have been proposed for the treatment of sewage, it may be as well to discuss shortly the apparatus or works necessary for the carrying out of any of them

Construction of Works

To carry out a chemical purification process it is essential to have

1. Means for adding the chemical to, and mixing it with the sewage
2. Means for bringing the sewage mixed with the chemical to a state of rest, or so near rest, that the precipitate formed may be allowed to settle.
3. Means for separating the clear liquid from the foul deposit.
4. Means for dealing with the sludge.

1. Means for mixing the chemical with the sewage. The chemical, whatever it be, is usually mixed first with a small quantity of water or sewage, and as far as possible dissolved, if it be soluble. This preliminary solution is a very important point, as thereby the full action of the chemical

is obtained, enabling a smaller quantity to be used efficiently, and consequently making the process more economical. It also reduces the amount of sludge to be afterwards dealt with. A great variety of means is used to attain this preliminary solution. Amongst others an ordinary mortar mill or specially designed mixing machinery is employed. Then the resulting mixture or solution may be added to the sewage in a salmon race, before passing through mechanical stirrers, or, if pumping be necessary, before passing through the pumps, which effect a very thorough mixing. Some reagents employed are not soluble. In some processes, where two or more chemicals are used, it is essential that one should be added to the sewage before the others. In that case two mixings must be undertaken. Constant care and attention are required in adjusting the quantities of chemicals employed, not only to the quantity of sewage coming to the works, but also to its quality or strength, if any degree of success is expected to attend the process. Neglect of this precaution often causes failure

2. Means to bring about subsidence of the precipitate. In almost all chemical processes the object sought to be attained is to throw down as a precipitate as much as possible of the noxious matter, whether in suspension or solution, contained in the sewage. Having thoroughly mixed the sewage with the chemical so that every particle or drop of it shall have been subjected to the action desired, it is necessary to bring the mixture as near to a state of absolute rest as will allow the precipitate, which has formed, to subside and separate itself from the water and substances which have escaped precipitation. For this purpose the mixture is run into tanks, of which various forms are in use.

(a) Rectangular Tanks: The ordinary tank in use in this country is of rectangular shape. It measures approximately four times in length what it does in breadth; it is deeper at the inlet end than at the outlet. It must not be too shallow, otherwise the flow of sewage through it will disturb and carry off the deposit. The floor or bottom is segmental in cross section. There are sludge doors (for the removal of the sludge) at

the bottom at the deeper or inlet end. The reason for these details is that most of the deposition takes place near the inlet end of the tanks, hence the sludge can be swept towards this end and removed, after the clear liquid has been drawn off, with less labour than if the opening for it were situated at the outlet end. Such tanks are generally constructed of masonry or brickwork with a concrete bottom; the walls and floor should be as smooth as possible to facilitate cleaning. They are often divided into compartments by transverse division walls, which do not quite reach so high as the surface level of the sewage, and so allow it, after filling one compartment, to flow over into the next, and so on. Between these walls, and also placed transversely to the length of the tank, are placed scum-boards, which intercept any floating matter, that may have passed into one compartment, and prevent it going on to the next.

Several questions have to be considered in planning and using these tanks.

(1.) Shall the flow be continuous or otherwise? Should the sewage be allowed to flow continuously and slowly through the tank,

or should the tank be filled and allowed to remain without admitting any more sewage for some time? The latter method, as we should expect, allows subsidence to take place more thoroughly; but it has this disadvantage that, after drawing off the clear liquid, you cannot fill the tank again without stirring up to a certain extent the foul deposit lying at the bottom, unless you have the tank cleaned out after every filling. This adds greatly to the expense. Accordingly the continuous-flow system is perhaps the method more frequently resorted to. In any case the sludge must be removed, and the tank thoroughly cleaned out, at least once in three days.

(2.) What rate of flow shall be allowed when the continuous system is adopted? It has been found that, in order to ensure good subsidence, about two hours must elapse between the entry of the sewage at the one end of the tank, and its exit at the other.

(3.) What shall be the capacity of the tanks? Experience shows that we may expect nearly eight per cent of the total daily flow to reach the works occasionally in one hour. Now, since the sewage must remain in the tanks for two hours, the

tank capacity provided must at least be equal to sixteen per cent of the daily flow. A second tank is required for use while the first is being cleaned; a third must be provided for emergencies such as heavy rainfall. For although the separate system of sewers be in use, a certain quantity of rain must reach the works, for instance that from back-yards, and the first washings of streets. So that, in the case of small works at any rate, it is necessary to provide a total tank capacity amounting to very nearly 50 per cent of the daily flow of sewage in dry weather. In larger works of course the tanks are much more numerous, and thus a much smaller proportion of the total tank capacity is out of use at one time for cleaning purposes, therefore a relatively smaller tank capacity is required.

(b.) Mr. Frank Candy's Tank — This tank is described by Prof. H. Robinson (Sewerage and Sewage Disposal, page 78). Instead of being rectangular in shape it is circular, and it has a flat bottom. This shape is adopted with a view to facilitate the peculiar method by which the sludge is removed. In the centre of the

bottom a horizontal pipe is pivoted so that it will just clear the floor; it is of sufficient length to reach the circular wall. This pipe is pivoted on another, which is carried below the bottom of the tank to the outside, and then up to within a foot or so of the full water level of the tank. The pivoted horizontal pipe has perforations on its under surface, and during the cleaning of the tank it is slowly revolved by hand from the outside. It is clear that in one revolution it will cover the whole surface of the bottom of the tank. When allowed to do so, the pressure of the water in the tank forces the sludge through the pipe, and out to the level of its opening, whence it can be run out into a pit or other receptacle prepared for it. It is claimed that by this method the sludge obtained is thicker and therefore less bulky than that drawn from ordinary precipitation tanks. Another advantage is that the continuous flow of the sewage through the tank is not interfered with by the cleaning.

(c.) Kriebühler Tanks. — The tanks known by this name are in use at Dortmund and Chicago amongst other places.

they are quite different in principle from those already described. They are vertical tanks, and for a considerable part of their depth they are cylindrical. The lower part of the tank takes the shape of an inverted cone. The sewage having been mixed with the chemicals (lime and sulphate of alumina, added separately and with a little interval between) is conveyed down a zinc cylindrical shaft, placed in the centre of the tank, as far as the foot of the cylindrical part. There it is spread out by means of radiating distributing arms throughout the area of the tank. When it has come nearly to rest the flocculent precipitate thrown down by the action of the chemicals begins slowly to settle. The sewage still coming into the tank must rise through this falling precipitate and it is to some extent filtered by it. The precipitate ultimately reaches the lower conical portion of the tank, and is removed through a pipe, which passes from the lowest point of the conical base up the inside of the inlet shaft. It is drawn up by means of a vacuum, and is best removed ~~removed~~ during a resting period, when no

fresh sewage is coming into the tanks; it then contains less water and is less bulky. The clear liquid flows away at the top by an arrangement of channels, which receive it from all parts of the surface simultaneously, so that the upward flow is made as equal as possible throughout the whole area of the tanks. Very good results are said to be obtained by this system, provided that all gross solid matter is kept out, and that the sludge is not allowed to accumulate and get old. The great advantage of this form of tanks is that it takes up so little room. The dis-advantages are that being almost constantly full the sides are apt to become very foul, and that there are difficulties in the removal of the sludge.

A Kenicbühler Tank, 30 feet in diameter by 30 feet in depth in its cylindrical part, and 15 feet in its conical part, will clarify 400,000 gallons of sewage per day and costs about £450. Except during resting periods for the removal of the sludge, the flow is continuous.

3. Means for separating the clear liquid from the foul deposit. These have

been referred to in the description of some of the forms of tanks. In the ordinary rectangular tank, used on the continuous flow system, the separation is accomplished during ordinary working by making the clear supernatant liquid fall over a weir at the end of the tank opposite to that at which it entered. In the absolute rest system, and in the continuous flow system when it is desired to empty the tanks for cleansing purposes, it is necessary to use other means, which must avoid disturbance of the sludge deposited at the bottom. The commonest device is the floating arm valve, which may be described as follows:— a sluice valve, leading into an effluent pipe or drain, is fitted near the bottom of the tank; to this is hinged a movable arm provided with a hollow vessel at its free end. The mouth of the arm lies at a lower level than this vessel, which floats on the surface, and so keeps the mouth just a little submerged. Thus the clear liquid can be removed without disturbing either the sludge or the surface scum. Another plan is to

fit to the end of the tank an automatic weir, which is so constructed, that its height is mechanically regulated by the depth of the liquid in the tank, and rises and falls with it. The methods adopted for the removal of the sludge from the various forms of tank have already been described.

4. Means for dealing with the Sludge. This is perhaps the greatest difficulty which besets all precipitation processes. So great a difficulty is it that the Committee appointed by the Corporation of Glasgow in 1880 to enquire into the various methods of sewage disposal say in their report- "The sewage sludge is the troublesome, not to say dangerous element in all such processes, especially that from lime precipitation, which changes more rapidly than that produced by the action of alumina or oxide of iron. The first and absolutely essential preliminary to the adoption of any method of treatment by precipitation is to arrange for the systematic removal of the sludge from the works. To begin sewage treatment without this, is to end in the creation of a gigantic nuis-ance, and become

"involved in an almost hopeless struggle to suppress it."

The sludge has in many cases a considerable manurial value, and when precipitation works are first started in any locality, it may often be sold in small quantities and at a small price to surrounding farmers, gardeners etc. This can be but a small outlet, however, and as the quantity increases, its price goes down: soon the farmers get it for nothing, and finally have to be paid to take as much as they can dispose of, which is generally a very small part of the total amount produced. In the British Medical Journal of October 27th 1894 it is stated "From a return just issued by the Local Government Board showing the number of urban sanitary districts and contributary places in rural sanitary districts in England and Wales in which systems for treating sewage by precipitation are in operation, it appears that 174 urban sanitary districts treat sewage by precipitation, thirty-seven of which find the precipitates of saleable value." that is a little more than 21 per cent. "The prices

"paid for the precipitate vary considerably from 8d. per ton up to 3 shillings per ton. In some instances farmers are induced to cart the precipitate away if the Board bears part of the cost of carting. Of joint sewerage and drainage districts there are three which treat sewage by precipitation: of rural sanitary districts fifty-six, and of these twenty two have precipitates of saleable value" that is 39 per cent. Thus it appears that less than 40 per cent of works, presumably most advantageously situated for getting rid of their sludge in this way, get anything for it, and probably most of the others find it a considerable source of expense.

Sludge is a black mud composed of organic and mineral matters separated from the sewage by chemicals, and mixed with a varying proportion of these chemicals. At first it contains about 90 per cent of water. If allowed to accumulate for any time it putrefies, becomes very offensive and may cause a very serious nuisance. The quantity produced varies according to the character and strength of the sewage, and also according to the

particular process and the chemicals used. The average seems to be about 40 tons per million gallons of sewage. It increases enormously with any excess of chemical employed over what is necessary for the treatment of the sewage. Its manurial value is estimated at about the same as that of farmyard manure. What makes it so difficult to deal with, is its physical condition: it contains so much moisture, it is difficult to handle. The preliminary to any method of disposal of it must therefore be the getting rid of as much of this water as possible. To accomplish this object several plans have been tried. One is that of spreading the wet sludge out on filter beds composed of ashes; it is found, however, that very little fluid passes out through the filter, and what does pass is extremely foul. The greater part of the moisture lost by the sludge while lying on such a filter bed is removed by evaporation. In wet weather when the atmosphere is saturated with moisture this process must necessarily stop. The result at the best is a very sloppy and offensive mixture, in a con-

dition which makes it difficult to remove. Driving off the water by heat & is too expensive a proceeding to succeed. The filter-press is probably the best of all methods of getting rid of the water, (or a large proportion of it), reducing the bulk of the sludge, and making it reasonably portable. It has the great advantage that the sludge is dealt with at once as soon as possible after its production and is reduced to one-fifth of its original bulk.

"The filter-press is usually constructed of cast-iron plates, having recesses and drainage surfaces on each face, the projecting rim forming with its counterpart, when these are placed in a suitable frame, a space or cell. The surface of each plate is covered with a filtering medium of jute or hemp canvas, or other like material, and on filling the cell with the sludge to be treated, and applying pressure, either by pumping more of the material to be filtered into the chamber direct, or by interposing an accumulator between the pump and the press, to accomplish the same purpose with a more uniform pressure, the

"liquid is forced through the filtering medium, and passing along the drainage channels, escapes at the bottom of ~~the~~ each plate, the solids being retained in the cells. When the liquid ceases to flow from the press, it is opened and hard cakes are discovered, consisting of the solids separated from the original material treated, together with a varying percentage of moisture." (W. Santo Crimp. "Sewage Disposal Works p. 115.) The usual percentage of moisture found in these cakes is about fifty. The liquid draining away from a filter-press is very foul and very strongly alkaline. (a little lime is generally added to the sludge to make it press more easily.) It cannot therefore be allowed to escape. So it passes back to the tanks to be again treated, either alone or with the rest of the sewage.

In whatever way the excess of moisture has been reduced in the sludge, the latter still remains to be disposed of. The smaller the quantity of water remaining in it the easier will be its disposal. The methods that have been suggested and tried for getting rid

of the sludge are several, viz,
(1.) As a manure: we have already seen that some sanitary authorities not only get rid of it in this way, but succeed in obtaining a price for it.
(2.) By digging it into land; this plan is suitable when there exists land for the further treatment of the tank effluent.
(3) For making cement:- Scott's Process
(4.) By burning it along with town's rubbish in a destructor of some kind; it is thus converted into clinker.
(5.) By steamship carriage to sea. This last method has been objected to because it is a waste of valuable manurial material, because of the possibility of its causing a nuisance on the coast, and on other grounds. Notwithstanding it remains the most suitable means, and the cheapest, for getting rid of the sludge in the case of a large town situated on the sea-coast or on a large estuary.

Different Chemicals Employed.

Having briefly described the apparatus required for the carrying out of chemical processes we are now in a position to consider the chief chemical substances employed in this way, their advantages and disadvantages, and the extent to which they perform the work asked of them.

Lime is by far the most frequently employed precipitating agent, either alone, or with some other substance. This is perhaps due to its cheapness, and to the fact that it is fairly efficient in clarifying sewage of almost any composition. Only the purest lime should be used, that containing much calcium, obtained from crystalline limestone. It should be well slaked before use – best the day before. The dose of lime employed depends on the character of the sewage and its strength, but it should be no more than will prove efficient; no excess must be allowed on account of the greatly increased amount of sludge produced, and the alkalinity of the effluent; besides it is supposed that, beyond a certain

dose, the lime rather tends to redissolve the organic precipitate. A very common dose is one ton per million gallons; much less may suffice if the lime is properly used. A ton per million gallons is equal to 15·68 grains per gallon. The great point to attend to in lime treatment is to get the lime dissolved; it should preferably be added in the form of lime water; if this is not possible, then as "milk of lime." The action of the lime is as follows:—

(1.) The lime combines with the carbonic acid in the sewage to form the insoluble and somewhat heavy carbonate of lime. This becomes deposited on any matters in suspension in the sewage, especially becoming entangled with light flocculent organic matter. These solids are so increased in specific gravity by the addition of the carbonate of lime that they subside.

(2.) The lime forms an insoluble compound with organic bodies in solution in the sewage.

Beyond these two actions the lime has no influence for good over the sewage. If more is added than is necessary

to produce these two actions, it simply increases the alkalinity of the effluent. The advantages of the lime process we have seen to be its comparative cheapness, and its efficiency as a clarifier. Against these may be placed the following dis-advantages :—

(1.) The quantity used requires very careful adjustment from day to day to the strength of the sewage in order to ensure the best results.

(2) It produces a very bulky sludge, which however is easily filter-pressed.

(3.) The effluent (and this is probably the most serious dis-advantage) is extremely prone to putrefaction. Should there be any excess of lime in it, if poured into a polluted river, it will cause precipitation in the bed of the river of the organic matter, and give rise to an extremely offensive deposit. The last two dis-advantages are very much minimised if the adjustment of the quantity necessary is carefully attended to.

Chloride of Lime is sometimes added with the lime (⅓gr to the gallon of

sewage), and acts principally as a deodouriser. It is useful during hot dry weather.

Sulphate of Alumina with Lime. The action of the two seems to be very much the same as that of the lime alone. The alum is generally added after the lime has been thoroughly mixed with the sewage the latter being rendered alkaline thereby. On the addition of the alum (also dissolved) some is of course precipitated by the alkaline sewage, some combines with organic matter in solution and carries it down with it. Experience seems to show that though the alum does not greatly increase the reduction of organic matter in the effluent, it very considerably reduces its tendency to undergo secondary putrefaction. So that the process has probably all the advantages of that employing lime alone, while the disadvantages are lessened. The dose of alum is usually about 5 grs. per gallon.

Protosulphate of Iron with Lime -

The protosulphate of iron, or ferrous sulphate, or green copperas, is employed with lime in the treatment of the sewage of London. The dose given there is 3.4 grs. of lime per gallon, and 1 grain of protosulphate of iron. It is found necessary during hot weather to add manganate of soda and sulphuric acid to the effluent to make it a little less offensive. This process has the same disadvantage as the lime process, namely, the quantity of lime requires to be very carefully adjusted

Ferric Sulphate Process — this is known as Wardle's Process. The action is assisted by the addition of a small quantity of lime. The reagent being added in the liquid form it does not produce much sludge. The dose is from 4 to 8 grains per gallon.

Black Ash Waste with Lime. — Black ash waste is the refuse from alkali works. The process has the disadvantage of producing great quantities of sludge. Speaking of an effluent from this process Professor Corfield says (Treatment and Utilisation of Sewage page 490), "Although

this effluent is similar in composition to a weak crude sewage, and has been kept in an open bottle for over a month, no putrefactive changes have taken place in it. Its sediment has contained, during the whole of the period, numbers of infusoria, which are as abundant and active now as on the day the sample was taken. It thus appears that although black-ash waste may prevent the formation of putrefactive organisms (Bacteria) when used in sufficient quantities, it does not interfere with the growth of those microscopic organisms, which, by feeding on organic matters are capable of purifying foul waters, without the production of foul gases of putrefaction." But the black-ash waste could hardly have produced the infusoria, whose presence (probably accidental) is quite sufficient to account for the non-occurrence of putrefactive changes in an effluent whose chemical composition suggests that it is very liable to undergo such a change (see pages 81-85). The keeping qualities of this effluent, then, cannot be attributed to the effects of the black ash waste.

the Amines Process consists in the addition of from 30 to 50 grains of lime per gallon, and 3 grains of herring-brine to the sewage. It has been tried at a number of places, and seems to fulfil the special claims that were made for it, namely, that it sterilised both sludge and effluent, and that consequently the sludge did not putrefy, nor was the effluent liable to secondary putrefaction. Dr. Klein and Mr. Cassal made experiments to ascertain the truth of this, and they both found the effluents to be either absolutely or almost sterile. Dr. Klein also made experiments with the "Amines" precipitant on specific organisms. He states that "the effect of the treatment was most powerful. The bacilli of typhoid fever, diphtheria, grouse disease, anthrax, and the micrococcus of ordinary suppuration are totally destroyed" (British Medical Journal, Nov. 1st, 1890). The sterility of the effluent appears also to be well maintained for some considerable time after its discharge. This process, then, must form a distinct advance where the effluent from chemical precipitation tanks cannot be further treated, (e.g.

applied to land), but must be poured into a small stream which is already polluted.

A. B. C. Process. Here for the first time we have to consider a process in which no lime is used. The chemicals employed, or the principal ones, are alum, charcoal, or the refuse from prussiate of potash works, and clay. Blood was used at one time — hence the name of the process. The clay and charcoal are ground together in a mortar-mill and washed towards the sewage; the alum is dissolved and added to the sewage afterwards. The action is as follows:- the alum produces a flocculent compound with the organic matter in solution; this precipitate entangles the clay and the charcoal, the former acting as a weighting material and the latter as a deodouriser. The precipitate falls and the sewage is clarified. On account of the insoluble nature of some of the precipitants, a large quantity of sludge is produced, but it is said to be valuable.

The Ferozone and Polarite Process is a

double process, involving, first, precipitation by the addition of "Ferozone" to the sewage, second, filtration through an artificial filter of which "Polarite" forms a part. "Ferozone" according to Professor Roscoe (quoted by Santo Crimp, Sewage Disposal Works p. 81) Consists of:-

Ferrous Sulphate	26.64
Aluminium Sulphate	2.19
Calcium Sulphate	3.30
Magnesium Sulphate	5.14
Combined Water	8.20
Moisture	24.14
Silica	11.35
Magnetic Oxide of Iron	19.01

The dose is about half a ton per million gallons, and is ground down with water or sewage in a mortar-mill. Its deodourising effect is said to be good, but it is not a good clarifier, and the effluent requires to go through the second part of the process viz. filtration. The filter is variously constructed: it is generally composed of layers of sand, gravel, shingle, and polarite arranged in various ways. Polarite is composed mainly of magnetic oxide of iron and has no special virtue in the filtration or

purification of sewage beyond its physical characteristics. Anything equally insoluble, and capable of making an equally porous filter, acts quite as well. Lately, the patentees have constructed a filter specially designed for aëration. About the middle of its depth, and above the layer of polarite, is a layer of gravel or stone the size of which is 1 inch to 1½ inches. Into it are brought 3 inch vertical pipes from the surface, placed about 6 feet apart, and at each side of the filter. Those at the one ~~des~~ side descend into the aerating layer and bend inwards in it; they are meant to act as inlets. Those on the other side are provided with outlet cowls (Robinson, Sewerage and Sewage Disposal. page 139.)

The second half of this process, or the filtration, does not properly belong to this division of the subject of Sewage Disposal (chemical methods); we shall see afterwards that it rather comes under the Bacteriological Processes.

Suffice it to say that the process is an efficient one, but the materials employed are very expensive

The following analyses by Sir H. Roscoe

are quoted by Robinson (op. cit. p. 138.)- They are analyses of effluent from the precipitation process, before and after it has passed through the polarite filter. The figures stand for grains per gallon.

	Unfiltered	Filtered
Chlorine	4·34	4·48
Free Ammonia	0·44	0·284
Albuminoid do.	0·050	0·018
Oxygen absorbed from permanganate in 4 hours	0·459	0·228

These filters will be again referred to.

The Massachusetts Experiments.

From 1888 till 1892 careful experiments on the treatment of sewage by chemical precipitation were made at St. Lawrence by the Massachusetts State Board of Health. The various chemicals were compared with one another both as to efficiency and as to cost. The report says: "The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is in-

"ferior to that obtained in other ways.

"Precipitation by Copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done, a good result is obtained. The amount of iron left in the effluent is much greater than with ferric sulphate owing to the greater solubility of ferrous hydroxide.

"Ferric Sulphate and Alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime, or any chemical, to the sewage.

"The results with ferric sulphate have been on the whole more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable from the greater ease with which ferric sulphate is precipitated that it would give a good result with a sewage that was

"not sufficiently alkaline to precipitate alum at once.

"It is quite probable that the same process would not give equally good results upon all kinds of sewage. Special sewage may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another."

In these experiments it was shown that the best chemical treatment left one third of the organic matter of the sewage in the effluent.

[When not otherwise stated, the information regarding the Chemical Processes has been derived from "Sewage Disposal Works", W. S. Crimp. 1894, "Sewerage and Sewage Disposal" H. Robinson, 1896, and "Parkes Practical Hygiene" 1891.]

Disposal of Manufacturers' Refuse

Before leaving the subject of the Chemical Processes, I propose to describe two cases of works carried on for the purpose of purifying the discharge from factories employed in the production of woollen goods. The effluent from such establishments contains chiefly substances which have been employed in the processes of scouring and dyeing the wool, such as oil, soap, alkalies, mordants, log-wood, alizarine dyes, besides the grease and other organic matter from the wool itself. The indescriminate discharge of such a liquid into a stream undoubtedly gives rise to a nuisance more apparent to the eye than that which would be caused by an equal amount of domestic sewage. It seems from the experience of most manufacturing districts, that the addition of such liquids to the ordinary sewage increases the difficulty in treating the latter out of all proportion to the volume of the addition. It follows then, that these discharges should be treated by the manufacturers themselves before their admission to stream or sewer.

Works No 1. In these works the "Magma Process" for the recovery of the oil from the refuse was formerly used. It has now been discarded, because the firm finds that magma made from "wool-scourings" is unsaleable, no one will have it; the only saleable magma is made from "web-scourings" which contain only fine oil and soda. It is therefore found to be more profitable to use these "web-scourings" over again for scouring the wool, than to convert them into magma, and use fresh oil and soda for the wool-scouring. The "web-scourings" are pumped up into two tanks in the scouring-house, and are drawn thence as required for the treatment of the wool. The effluent from the wool-scouring machines passes into a small tank in the open air, where the grosser impurities separate from the liquid by simple settlement. Thence it flows over a sill into a larger storage tank; there it remains till it is pumped up into wooden or iron precipitation tanks under cover for treatment. It is not subjected to any treatment till it reaches them.

The remainder of the discharge from the factory requiring treatment consists of the effluent from the dye-house. This consists of two different fluids — one containing the mordaunt, usually a solution of bichromate of potash, the other the "black-water" or dye-stuffs. The dye-stuffs consist mainly of log-wood and aliyarine dyes. These two fluids on arriving at the works are admitted to the same tank after passing through a sieve which removes large particles such as log-wood chips, pieces of wood etc. The storage tank in which they are received is L-shaped: the inlet is situated at the free end of one limb of the L, the outlet at the free end of the other, so that they are as far apart as possible. This ensures that the mordaunt and the "black-water" become very thoroughly mixed in their passage through the tank: the mixing is further assisted by hand stirring. The two fluids react on one another, and some precipitation occurs. While in this tank the fluids have added to them about 40 lbs of vitriol and the same quan-

tity of "alumino-ferric" each day,— half the quantities mentioned are added twice daily. The addition of these chemicals is stated to be necessary to assist the action of the already acid dye-house effluent on the scouring water, whose reaction is alkaline, in the next step in the purification process.

We have now two storage tanks, the one containing alkaline scouring-water, as yet untreated, the other the mixed mordants and dyestuffs, in which some precipitation has occurred on the mixing of its two components, and to which vitriol and "alumino-ferric" have been added. The next step in the process is to bring the contents of these two tanks together. This is done in the Precipitation Tanks. They are situated under cover, are three in number, and each is divided into two compartments. They are constructed of wood, but it is found that the chemical action is too much for the wood which gradually crumbles away, so they are being replaced, as necessary, by iron tanks. The process carried out in these tanks is as follows:— First the alkaline

scouring water is pumped up, till the compartment of the tank is about one third full or a little more, then the cock of the pump is altered, so that it fills the remainder of the compartment with the acid dye-water and mordants (with the added vitriol and alumnio-ferric) During this latter pumping the mixed dye-water and mordants are stirred up in the storage tank, so that the precipitate formed on their mixture is sucked up along with the liquid. Each compartment of the precipitation tanks holds about 5000 gallons. The inlet pipes are carried right down nearly to the bottom to ensure, during the filling, the thorough mixture of the contents. When the tank has been filled there is added about 60 or 70 lbs of finely powdered lime. Then the cock of the pump is again altered, and air is forced through the liquid, further mixing the contents and bringing about solution of the lime. The air-pumping is continued for about half an hour; at the end of that time a sample of the mixture is taken in a small glass. If the precipitate falls

quickly, and leaves a clear supernatant liquid, the air-pumping is stopped, and the contents of the tank allowed to settle. If the precipitate does not settle quickly in the sample, and if it leaves a turbid liquid at the top, the air pumping is continued. It may also be necessary to add a little more lime. The process is continued till the precipitate falls rapidly and a satisfactory liquid is left.

After the precipitate in the tank has had time to settle completely, the supernatant liquid is drawn off, passed through a storage tank where some further slight subsidence takes place, thence through a filter bed composed of ashes arranged in layers (the smaller on the top), and finally discharged into the river. The ash filter seems at least to retain any scum which may have been drawn off from the precipitation tanks, and to improve the appearance of the effluent. The effluent after being kept for a month, as well as immediately after its discharge, is quite clear, throws down practically no deposit, and is either quite odourless or has a very faint alkaline odour.

It is generally quite colourless, but occasionally it is of a very slight greenish tinge.

When the fluid has all been drawn off from the precipitation tank, a sluice is opened and the precipitate is allowed to run out into beds immediately below the tank, which contain some filtering material, composed of ashes in the lower layer, and a mixture of sawdust and logwood chips. ~~At first~~ Sawdust alone was used on the top of the ashes, but it was found that it ran together, caked and clogged. The mixture of saw-dust and logwood chips seems to act very well. The fluid from the sludge drains through this bed, and flows away back to the storage tank, where the mordaunt and dye-water are mixed, to be treated over again. The sludge itself dries, and when it has become of a convenient consistence, it is removed in barrows to a large heap on vacant ground, and for the present is there stored. It seems to have no tendency to undergo putrefaction.

The volume of refuse liquid treated daily amounts to about 25,000 gallons

from the dye-house, and about one third of that quantity from the scouringhouse The six compartments of the precipitation tanks are each filled and ~~em~~ emptied at least once in the day — some are used twice.

Works No 2. These works differ from those we have been describing in that the "Magma" Process for the recovery of oils from the refuse is carried out. The scouring water containing chiefly oil, alkali and organic matter from the wool, and consisting of both web and wool-scourings is collected in a storage tank in the open air. Formerly the web and wool scourings were kept apart and treated separately, but this was given up. From the storage tank the liquid is pumped up into wooden tanks placed under cover. There are four of those, and each one measures twelve feet by seven in area, and is seven feet deep; it therefore has a capacity of about 3600 gallons. When the pumping has filled about three quarters of one of those tanks, a carboy of vitriol (about 1 cwt. 3 qrs) is poured in, and

thereafter the pumping is continued till the tank is full. To each tank there are two inlet pipes passing down to, and opening, near the bottom of the tank, so that thorough mixing of the contents is ensured during the filling process, the liquid entering with some considerable force. The tank and its contents are then allowed to stand for about two days, when the liquid is ready to be drawn off. The magma floats on the top of the clear liquid. The drawing off is accomplished by a pipe, which runs vertically up the outside of the tank, communicating with the inside by about half-a-dozen stop-cocks at different levels. These cocks are opened and the liquid is allowed to flow away to another storage tank in the open air. Whenever the flow begins to get a little cloudy, the uppermost cock is shut, and so on until the lowest has to be closed. This leaves the "magma" in the tank. The process is then repeated. After the tank has been filled with scourings about eight times, the magma which has accumulated is removed, by allowing it to flow out onto a filter

bed composed of (1) layers of ashes (the coarser below, the finer above) and (2) a top layer of mixed sawdust and logwood chips. There the magma accumulates for about three weeks; during that time it dries to such a consistency that it can be packed into iron receptacles, and sold to oil-refiners. The liquid passing through the filtered drains away to the same storage tank as that drawn off before, and mixes with it.

The "black water" from the dye-house is stored in another large tank in the open air. It contains both mordants and dye-stuffs with all other refuse water from the factory except the scourings. While flowing into this tank over a shallow sill, it has added to it a quantity of finely powdered lime. The lime is added by hand and stirred up with the inflowing liquid on the sill, and afterwards in the tank itself. The amount of lime is not accurately measured, but seems to be just as much as the liquid will take with it. The addition of the lime renders the reaction alkal-

me, previously it was pretty strongly acid. This alkaline mixture is now pumped up into one of ~~the~~ another series of tanks under cover, exactly similar to the set used in the magma process. Each tank is filled to about the extent of two-thirds with this alkaline fluid, the remaining third is filled up with the acid water drawn off from the magma tanks. The same arrangement of inlet pipes, to insure thorough mixing up of the contents of the tank, as were mentioned in describing the magma process, are employed here. The system of blowing air through the contents of the tank was formerly employed as an aid to the other means, but it was found unnecessary and has been discarded. The necessity for it is probably done away with by the addition of the lime to one of the liquids before it passes through the pumps. The mixed fluid having remained quiescent over night, the supernatant liquid is ready to be drawn off in the morning. This having been done, it is passed through a small ash filter and allowed to flow into the river.

The deposit left in the tank is treated as before, namely, allowed to run out onto a filter-bed placed immediately below the tank, and composed of sawdust, logwood, and ashes. It lies there till it becomes of a consistency suitable for removal in barrows. It is entirely a waste-product - no one will have it at any cost. Any liquid which passes through the filter-bed flows away back to one of the storage tanks.

"Magma" consists mainly of fatty acids which are set free by the action of the sulphuric acid.

Electrical Processes.

Under this heading two processes fall to be described. They both seek to employ electricity in the treatment of sewage, the first directly, the second indirectly.

The Webster Process is an endeavour to subject sewage directly to the action of the electric current, thereby to secure the breaking up and oxidation of the noxious organic matter contained in it. It was first tried at Crossness, but has since been experimented on at Salford and Bradford. The process is described by Mr. Webster in "Sewage Disposal Works" by W. S. Crimp (p. 329 et seq.), and by Dr. McCulloch, British Medical Journal, Augt. 30th, 1890.

The plant necessary is as follows:-

(1.) A shoot in which the process takes place.
(2.) Settling tanks.
(3.) A so-called electric filter
(4.) Some form of generator
(5.) Motive power for the generator

The shoot is constructed of brick-work and is of an elongated form; it is divided into cells by partitions which allow

of the sewage passing over and under them alternately. In these cells are placed the plates or electrodes, which are constructed of iron of the commonest kind. In each cell the plates are placed parallel to one another and to the direction of flow of the sewage. Every alternate plate is connected respectively with the positive and negative poles of the generator. The generator consists of a dynamo. After flowing down the shoot through the whole series of cells the sewage passes into settling tanks. Then it may be conducted down a second shoot and again subjected to the current. The shoot should be lined with asphalte, which forms an excellent non-conductor, and prevents leakage of the current. Mr. Webster states that he has proved by actual experience that there should not be less than 25 cells or series of electrodes.

The principle of the process depends on the fact that, when subjected to electrolysis, water and chlorides (which of course are always present in sewage) are split up into their constituent parts. Then oxygen and chlorine appear at the

positive pole in a nascent state, ready to attack and combine with everything available. In this case, with iron electrodes, the oxygen combines chiefly with the iron. The action is thus described by Mr. Webster, "The electric action is easily explained. At the positive pole the chlorine and oxygen given off combine with the iron to form a salt, which is doubtless for the moment a hypochlorite of the metal, but it immediately changes into a chloride, which in its turn is deprived of chlorine to form ferrous carbonates and oxides. During the chemical action carbonate of iron exists in solution, and its formation is due to the presence of carbonate in the sewage, chiefly carbonate of ammonia. In samples that are absolutely free from dissolved oxygen the ferrous oxide in the white form is precipitated, and on shaking it up with air it changes to the usual pale green colour; the carbonate of iron being at the same time oxidised, the ultimate red precipitate is known as Ferric Oxide, Fe_2O_3, and sometimes this changes after a time back again to the Ferrous state, FeO, thus showing that it has acted as

"a carrier of oxygen to the organic matter present. On a small scale the precipitate is carried to the top, due to the bubbles of hydrogen collecting round the particles of matter in suspension, but it ultimately sinks in the usual manner. In practice the precipitate does not rise owing to the larger evaporating area, which allows of the escape of the gases produced."

It has been doubted whether the whole purifying influence of the process were not due to the formation of the salts of iron, and could not be produced by simply adding them to the sewage, without employing electricity at all.

During the process a greasy scum collects on the surface of the tanks and on the iron plates. This is collected into a small tank for the purpose.

Dr. Mc. Livtock gives the following analyses:-

	Sewage	Effluent
Total Solids	124 grs. per gallon	66
After ignition	69 " " "	47
Loss on ignition	58 " " "	19
Chlorine	10 " " "	9
Free Ammonia	3·2 parts in 100,000	2·1
Albuminoid N.	1·5 " " "	·5

the process seems to yield a fairly good effluent which contains about 3 grains per gallon of suspended matter, mostly iron. This can be removed, and the effluent still further improved by passing it through the electric filter, formed of alternate layers of small coke and either sand or perforated tiles. These layers are connected alternately with the positive and the negative poles.

The drawback to the system is the somewhat large initial outlay, and annual cost for electric power and upkeep.

The sludge formed must be dealt with in the same way as that produced by other processes. It is said, however, to be small in amount and not liable to putrescence.

The Hermite Process. In this case electricity is indirectly employed for the purpose of treating sewage, deodourising and sterilising it. An electric current is passed through sea-water. The effect of this is electrolysis is that the chlorides, always abundant in sea-water, are decomposed, and the water becomes charged with free chlorine. The

sea-water, so charged, is laid on to houses, public conveniences etc. by a special system of pipes: there it is used for flushing the water-closets and other tributaries of the drains. The system was investigated by Mr. J. Lunt B. Sc. and Dr. Ruffer at the British Institute of Preventive Medicine (British Medical Journal, June 9th, 1894.). They found that the chlorine solution produced was very unstable unless the electrolysis was carried on till a considerable amount of free available chlorine was present. Thus a solution of a strength of .5 gramme per litre lost 90 per cent of its strength in 24 hours; one of .75 gramme lost 34 per cent; while one of 1.05 per 1000 lost only 7 per cent in the first 24 hours. In connection with this matter they also found that the production of these higher strengths was somewhat costly, because an increase of the current employed of 100 per cent, produced only an increase of 50 per cent in the strength of the solution.

The action of this solution on the sewage is, according to Mr. Lunt & Dr. Ruffer, not all that was claimed for it by

M. Hermite. He claimed that it had a special disintegrating action on solid faeces, and that it thoroughly deodorised and sterilised the whole of the sewage. It was found during the above mentioned experiments, that the fluid had no disintegrating or dissolving action of solid faeces over and above that possessed by ordinary sea-water, and that therefore, even when employed of ample strength, it did no more than sterilise the outside of such solids. When the solids ~~are~~ were by some means reduced to pulp and thoroughly mixed with the liquid, the whole was sterilised, provided the latter was of the requisite strength. What is the requisite strength? It was shown that solutions of ·25 per 1000 were practically useless for killing bacteria, and that a solution of ·5 was only effective if employed very shortly after it had been made, and then only on such micro-organisms as do not produce spores. Higher strengths were naturally more efficient. "The only micro organisms which resisted even the gramme solution after one hour, and two hours' action were the spores of bacillus subtilis"

From this statement it must be apparent that it is of no use to prepare a liquid of less strength than 0·75 per 1000, since from the system followed it is impossible to use the fluid immediately after its preparation.

M. Hermite recommends the use of an intercepting basket in connection with water-closets. When this is used, and a fairly strong fluid employed to flush the closet, the effluent is found to be sterile; the basket however speedily becomes choked with solid faecal matter, which is anything but sterile. This must be periodically dealt with, either by breaking it up with some of the fluid, or by other means. Even were the System perfected in some of its details, it seems hardly likely that it can ever become practicable, in the case of inland towns at any rate. The laying of special pipes for conveying the fluid to individual houses would seem a heavy burden. It is said that it can be applied at outfall works and that the amount of the electrolysed sea-water required is 10 per cent of the volume of sewage. This must depend on its strength.

Bacteriological Processes

The principle, on which the chemical processes are planned, is that of removing bodily from the sewage as far as possible all organic matter in the solid form, and with it as many of the micro-organisms as are carried down with its subsidence. A portion of the organic matter is simply separated from the liquid; it remains to be dealt with in the sludge. Some chemical processes also aim at sterilising the fluid. With the electrical process of Webster practically the same end is had in view; it is claimed for it that it actually breaks up organic matter into simple innocuous substances, but it is doubtful to what extent this is true. The Hermite process seems to be simply one of deodorisation and sterilisation. In the processes now to be considered a different principle is involved. It is necessary in some of them that the ~~solids~~ grosser impurities should be kept back, or in some way removed from the liquid; but all the rest of the organic matter is dealt with in the liquid. It is submitted to the

action of agencies which break it up and convert it into substances of such a nature, that it matters not whether they remain in the liquid or are removed from it. These agencies consist of micro-organisms, which use the organic matter as food. Processes of this kind have been going on for the disposal of sewage since ever there was animal life in the world. They form Nature's method of destroying effete organic matter of all kinds. They have even been unwittingly employed by man for the systematic disposal of sewage on large scales, e.g. the land treatment of sewage. It is however only during the last twenty years that what takes place in, and what is at the root of these processes, has been understood and investigated. It is not wonderful that the processes devised before this period were in many cases not directed so as to help Nature, but were rather hinderances to her operations.

The history of the elucidation of the details of the process may be stated somewhat as follows. It came about through the application of sewage to

land. The object of this proceeding might be either the use of the land as a strainer of the sewage, that is, in the interests of the sewage, or it might be the enrichment of poor land by the fertilising material contained in the sewage. Now, in studying the requirements of the grass or other crop grown on the land so treated, the conditions necessary for the successful purification of sewage were unconsciously fulfilled. Thus the sewage was applied intermittently, and the total quantity passed was small compared to the area of the land. The necessity for the intermission in application, and the consequent aeration of the land, apart from the interests of the crops, seems to have been early recognised, but the meaning was not correctly interpreted. It was supposed that the interstices of the land were filled with air under compression, that the sewage came very minutely into contact with the oxygen of that air, and that the result was a simple chemical absorption of the oxygen by the organic matter in the sewage. When all the oxygen had been absorbed

it was of course necessary to remove the sewage (stop its application), and allow the air to permeate the soil again, and renew the supply of oxygen. If this had been true, the ability of land to purify sewage would have depended directly on its texture and porosity, would have varied directly as the number of thin films into which it could divide a given stream of liquid passing through it. Then again, on this assumption, the degree of purification, effected by any area of land on a given volume of sewage of constant composition, would have been exactly the same on the first day the land was used as on any other, allowing a little perhaps for variations in temperature and rainfall. When experiments came to be carefully made on the subject, it was found that none of these propositions held good. It was found in the first place that the power of soils to purify sewage did not vary directly as their fineness and porosity; to a certain extent their power did depend on these attributes, but differences between various soils cropped up which could not

be accounted for in this way. Again, it was found that soils, which when first experimented upon showed very poor results, very small degrees of purification, even when placed under the best conditions, that these soils if kept in use under these conditions, and used to pass sewage through for days, weeks, or months, gradually improved. They became more powerful purifiers, they acquired a power which at first they had not, or only in a very small degree. It was also found, that if a soil were deficient in the power of purifying sewage, (but not from any physical cause), it could be speedily rendered efficient by simply adding to it a small quantity of soil which had been already proved to be efficient. Now, these various facts could only be accounted for in one way, namely, that the process of purification in these soils was brought about by some agency, which was capable of growing and increasing under favourable conditions. In other words, the purification must be due to living organisms. These facts and theories were first in-

vestigated and called attention to by Schloesing and Müntz in 1844. They were published in 1848 in a Report to the International Health Congress in Paris. Their experiments were followed up by Mr R. Warrington of Rothamsted in this country. It will be well to detail the evidence they collected, and which formed a complete proof of the purification of sewage by living organisms. But first it may be necessary to mention the chemical changes in which the purification consists. The complex organic substances are first split up into simpler bodies, among which are carbonic acid, water, and ammonia, the latter being subsequently oxidised to nitrous acid and nitrites, and then to nitric acid and nitrates. When the process is complete, all the organic nitrogen, which has not passed off in some gaseous form, has been converted into nitrates. Thus the process of purification is essentially one of nitrification, and the relative amounts of nitrates and organic nitrogen (or albuminoid ammonia) in the effluent form an index of the degree of purifica-

tion which has been effected.
The evidence in support of the theory that this process of nitrification is due to the action of living organisms is as follows:-
1. The process is limited to a certain range of temperature, and this range corresponds to that in which living organisms are known to thrive. Thus the action becomes very slow as the temperature approaches the freezing point. On the other hand it increases as the temperature rises, and reaches its maximum at about 100° F. At higher temperatures it diminishes till it ceases altogether when the temperature has reached 131° F. But it will start again if the temperature be lowered, unless the temperature has been raised to 212° F, in which case no action will follow reduction of temperature. In this case to renew the action some fresh material, which has been carrying on the process, must be added to the soil. This means that the organisms ~~are~~ ~~it~~ necessary to the action are killed by exposure to the temperature of boiling water.
2. The presence of ordinary antiseptics such as carbolic acid, salicylic acid, etc,

stops the process.

3. The absence of phosphates from the soil is said to interfere with the action.

4. It has been found that the upper 3 or 4 feet only of soils possess the power of nitrification, and the upper six inches or so are the most active.

5. Food must be supplied to the organisms - this is amply provided by the organic matter in the sewage. If land be manured with ready-made nitrates alone for any length of time, the supply of food for the organisms will become exhausted, the organisms die out, and the land lose its power of nitrification (Wiley. Yearbook of the U.S. Depart^mt of Agriculture* page 93.

6. Unless oxygen be freely and frequently supplied the process stops; the organisms cannot live and carry on their work without it. If the supply of oxygen be deficient then nitrification stops and putrefaction sets in, as has been shown by Adeney and Parry (quoted by W. S. Crimp, Sewage Disposal Works p. 134 and 135) Putrefaction is a process of considerable interest in relation to sewage disposal; it is therefore necessary to consider it and the conditions attaching to it.

* for 1895.

Putrefaction is one of Nature's methods of getting rid of effete organic matter — the organisms concerned in it break up organic matter, but in doing so give off offensive gases, instead of decomposing it into simple inoffensive substances. Prof. Hamilton in his Text-book of Pathology. Vol. II. Part II p.p. 982 & 983 says, "It used to be said that there was one organism of putrefaction, namely, Bacterium Termo. It is now conceded, practically on all hands, that this is not a pure form, that the small cylindrical body so designated is nothing more than a stage in the life history of several different organisms. The truth seems to be that there are many organisms which have the property of inducing putrefaction"

"Hauser finds, on sowing some of the liquid derived from putrefying substances on the surface of gelatine plates, that many different colonies develope upon it. Most of these fail to liquefy the gelatine, but there is one met with in great constancy which does so, and which he regards as among the most important causes of putrefaction.

"He gives it the name of Proteus from the many forms it assumes. Thus beginning as a coccus-like ~~form~~ structure, it may pass successively through the stage of a short rod, a long rod, a thread, a vibrio, a spirillum, and a Spiro-chaeta. The multiformity of the organism is dependent apparently upon, and is regulated by, the nature of the basis on which it is growing, so that for instance, when grown on an acid basis, only cocci and short rods are forthcoming. He distinguishes three species, P. vulgaris, P. mirabilis, and P. Leukeri. They belong to the class of facultative anaërobes. Proteus Vulgaris and mirabilis are amongst the chief promoters of putrefaction.

"They can be subdivided into those which are aerobic and those which are anaerobic. The aerobes grow luxuriantly at first all through, let us say, an infusion of muscle, but as the oxygen becomes exhausted they pass to the surface, where they localise themselves often in the form of a film. The anaerobes can now flourish in the deep parts of the liquid unopposed and protected by the film of aerobes on the surface.

"The elements of the medium can be entirely oxidised by the ~~Bac~~ aerobes and converted into inodourous substances such as carbonic acid and water.

"Those acted on by the anaerobes are naturally less completely oxidised and are much more complex. Briefly summarised they are as follows:—

"(1) Hydration products: Leucin, leptone, amido-valerianic acid, tyrosin, glycocol

(2) Volatile products: Ammonia, volatile fatty acids, and reduction gases such as hydrogen, sulphuretted hydrogen, and marsh gas.

(3) Characteristic putrefactive products: Skatol, indol, and phenol.

(4) Basic Compounds or ptomaines.

"Hydrogen is liberated and combines with sulphur in its nascent condition, or with phosphorus, to form respectively sulphuretted or phosphuretted hydrogen. These add to and confer a special character upon the odour."

It is then the action of these anaerobic agents in the process of putrefaction that we wish to prevent when aiming at nitrification of sewage. From Adeney and Parry's experiments it would seem that they cannot thrive when the con-

ditions favourable to the growth of the nitrifying organisms are present, possibly on account of an antagonism between the two classes. The aerobic forms would not seem to be objectionable; what their connection with and relation to the nitrifying organisms is, is not very material from the practical point of view of sewage disposal. They may assist in the preliminary process.

Now, what means can we adopt to eliminate as far as possible these anaerobic forms when we wish nitrification to take place? They are as follow:-

1. The sewage must be placed under the influence of the nitrifying organisms as quickly as possible, so that it may be fresh, and the organisms of putrefaction may not have had time to multiply to any great extent.

2. The solids must be kept back. at least the coarser of them. We can easily understand that in the case of solids it is impossible to supply oxygen in any quantity to any part of the solid except the external surface. Accordingly the anaerobes will have free course in the interior of solid particles.

Besides, solids accumulate at the surface of the soil, or whatever medium is used for the cultivation of nitrifying organisms, clog it, and render difficult the next condition for the elimination of anaerobes.

3. The free supply of oxygen. If the nitrifying organisms are to contend for their existence with others, as well as perform their work satisfactorily they must have their own special conditions of life well attended to, and of these the most important is a free and a frequent supply of oxygen.

What has been said about these nitrifying organisms already, has referred more particularly to their action in a soil or some similar medium. They also act in fluid media, such as a river, if their necessary conditions of life are fulfilled.

It may be as well, before going on to describe these nitrobacteria and their favourite conditions more fully, to consider for a little what goes on in a river into which sewage is discharged. There, as in land, the undesirable event is the occurrence

of putrefaction, and this when it occurs, is always due to the defective supply of oxygen. But in the river these putrefactive germs have, it would seem, other enemies besides the nitrifying organisms. In the British Medical Journal of June 17th 1893, Harvey Attfield describes some experiments which tend to show that the bacteria in polluted river water are destroyed by Infusoria. "On July 1st two 1-litre flasks which may be designated A & B were sterilised. Into each of these was introduced about 500 c.c. of water drawn from a certain disused well. This water contained 10,000 bacteria per c.c. as estimated by counting the colonies on gelatine plates in the usual manner, but was almost free from infusoria. To A. was added 10 c.c. of River Isar water. The latter was collected about 150 metres below the influx of one of the main Munich sewers. The Isar-water contained much Beggiatoa Alba and swarmed with Infusoria. The latter were for the most part Paramoecia aurelia, and P. caudatum." Plate cultivations were made from

these, and then plates and flasks were placed in a cellar, because the temperature of the cellar resembled that of the well from which the water was drawn. Cultivations were made also on subsequent days. When the colonies came to be counted the following were the results obtained: —

	A.	B.
July 1st per c.c.	259.000 bacteria	10.000
" 2nd " "	364.000 "	
" 4th " "	48.584 "	
" 5th " "	44.500 "	5.000

"It thus appears that in the water (A) swarming with infusoria the bacteria had decreased to less than one-fifth of their original number in six days, whereas in the water (B) containing very few, if any, infusoria the decrease of the bacteria in six days was only one-half of their original number.

"The suggestion was here made that in the foregoing experiments perhaps light had something to do with the destruction of the bacteria, for a certain amount of direct sunlight had access to the cellar. In the next series of experiments, therefore, similarly pre-

hared vessels were protected from light by means of covers of black card-board."
"The contents of the two bottles were kept in constant movement by blowing a slow current of air through each bottle by means of a forcing-air-pump, the air being filtered through plugs of sterilised cotton-wool. The water used in these experiments was, for A. collected 150 metres below the influx of the main Munich sewer into the Isar. It contained some beggiatoa alba and infusoria. For B. the water was collected from the Isar above Munich. The methods of procedure, namely, making plate cultures and counting the colonies, were carried out as in the previous series of experiments" Prof. Attfield thus summarises the results of this series:- "Here again the proportional amount of decrease of bacteria between the water with infusoria, and that without them is very marked. In A the decrease is as from 500 to 1, while in B it is not quite as from 1½ to 1."
Another series of experiments was conducted with a view to ascertain the

effect of the driving of air through the fluid. Prof. Attfield says, "we find there is very little difference in the proportional decrease of bacteria whether air be driven through the fluid or not".

"In this series of experiments very interesting ocular evidence of the purification that was going on was noticed, namely, the water in the A bottles became quite bright and clear, while the water in the B bottles became thicker and more turbid. Prof. von Pettenkofer, to whom I showed these bottles, was particularly struck by this point. In this series the presence of infusoria seemed to have a more marked effect than in the foregoing experiments. For, in ten days, a water containing 3,000,000 bacteria per c.c. decreased in bacterial contents to a little over 13,000, while the water containing no infusoria not only gave no decrease in numbers, but rose in bacterial contents from 400 per c.c. to 121,500 in the same time, namely, ten days.

"From these experiments it would seem that infusoria have some powerful in-

"fluence in the getting rid of bacteria, and possibly so aiding in the "self-purification" of water."
Very likely Prof. Attfield is right in attributing this power to infusoria; but the presence of infusoria was not the only point of difference between the water in the (A) and that in the (B.) bottles. There was a very great difference in the numbers of bacteria in the respective bottles, and it seems to me that this might have accounted very largely for the greater proportionate decrease in the A bottles, quite apart from the presence of infusoria.
While this process of purification goes on in the laboratory it seems also to take place in nature. Dr. Percy Frankland (Micro-organisms in Water pp. 100-102) refers to observations which he made on the River Dee during 40 miles of its course. He found that the river was polluted at numerous points during that flow, and that immediately below each point of pollution the micro-organisms were very numerous in the water. They gradually diminished in numbers

as the water flowed on, until they were again increased by the next pollution. He states, however, that he cannot exclude the factor of the dilution ~~to~~ of the water through the increase in volume of the stream.

Organisms concerned in Nitrification: We must now return to the process of nitrification, and consider the organisms to whose action it is due. Of these there are three sets or kinds which have each their own particular duties. The members of the first set are not strictly speaking nitrifying organisms, but their action is essential if complex organic bodies are to be submitted to that of the other two kinds. The three sets are as follow:—

(1.) Organisms which break up organic compounds, forming ammonia or carbonate of ammonia.

(2.) Organisms which convert ammonia into nitrous acid and nitrites

(3) Organisms which convert nitrous acid and nitrites into nitric acid and nitrates

The first group probably includes a very large number of different organisms among which may be the aerobic or-

ganisms concerned in putrefaction. Large quantities of ammonia and carbonate of ammonia are produced by them. The organic carbon is also oxidized and thus carbonic acid is produced and certain organic acids. Any organic sulphur becomes converted into an acid.

The second group seems to consist of one definite organism. It is large and vigorous, a slightly oblate micrococcus, multiplying by spores.

The third group consists of a much smaller organism — about one-fourth of the size of the preceding. It has no action on ammonia. (H.W. Wiley - Year-Book of the U. S. Department of Agriculture for 1895, page 75.)

Now, what are the conditions under which these organisms best carry out their functions? Some of these we have already considered, but it can do no harm to repeat them along with the others in order to complete the list.

1. All three groups require an alkaline, or at least a nearly neutral, medium. The first group (the ammonia producers) of course themselves bring about alkalinity. It seems that their

activity is not wholly destroyed by a slight excess of acid, provided the acid does not exceed one per cent (Wiley, loc. cit.) The other groups tend to produce acidity, and this acidity paralyses them. It must therefore be guarded against; this can easily be done by having present in the medium in which they are working some base such as lime, which unites with the acids as soon as they are formed and neutralises the acidity. Practical proof of the necessity for this precaution is furnished by the fact that land which has become sour is non-fertile.

2. A certain range of temperature is essential for their activity, as we have already seen. When once in full working order the organisms themselves tend to raise the temperature of the medium in which they grow, hence the action is not stopped when the temperature of the air falls below freezing point. (Dibdin. Report to London County Council October. 1895.)

3. Absence of Light. Sunlight has a very prejudicial effect on their activity, therefore they are not active on the very surface of a soil (Frankland. Op. cit. Chap. 9.)

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4. A plentiful supply of food is necessary. In the treatment of sewage, the organisms are abundantly supplied in this way by the organic matter in sewage. The nitrifying organisms proper refuse to grow on the ordinary solid culture media employed by bacteriologists, namely, gelatin-peptone. It has been shown by Munro and Winogradsky that they can take up nourishment, multiply, and form protoplasm from a medium destitute of organic matter. The following is a solution in which they have been grown: —

Ammonium Chloride	·5 grm.
Potassium Phosphate	·1 "
Magnesium Sulphate	·02 "
Calcium Chloride	·01 "
Calcium Carbonate	5·0 "
Distilled water	1 litre

The difficulty of getting a solid medium on which they would grow has been overcome by Prof. Kuhne. He converted a solution similar to the above into a jelly by the use of silica (dialysed silicic acid) (Prof. P. F. Frankland, Nature, June 9th 1892). From the fact that they can grow on media destitute of organic

matter, it is probable that the nitrifying organisms form a considerable element in the disintegration of rocks. (H.W. Wiley loc. cit. page 71.)

5. If it is desired that these organisms should carry out their work on organic matter in a liquid, their efficiency is very much enhanced if they are provided with some kind of scaffolding throughout the body of the fluid. They attach themselves apparently to the scaffolding, and by its help are they most rapidly distributed throughout the fluid, and enabled to come in contact with every drop of it. They use the surfaces and pores of such a scaffolding as operating tables on which they carry out their work of destroying and oxidising the organic matter. Then it is probable that when such scaffolding is covered with the liquid, its pores and interstices retain a certain amount of oxygen, this further aiding the work of the micro-organisms. For this purpose a variety of materials has been used such as soil, gravel, sand, shingle, broken stone, and coke.

6. A plentiful supply of oxygen. This

we have already considered. It is because of this need, that these nitrifying organisms are not found in ordinary soils beyond a certain depth, four or five feet. There is no reason why, in a specially constructed medium they should not be supplied with plenty of oxygen, and made to grow and thrive at a greater depth than this.

7. Absence of large solids from the liquid to be treated, we have already considered.

Now, are there any other agencies which may help in the destruction of organic matter and the consequent purification of sewage?

a. Agencies which reduce nitrates may possibly assist in certain circumstances: they consist of a great number of bacteria, certain germinating seeds, the tubers of potato, and certain fruits (Hamilton, loc. cit. pp. 995-6)

b. Plant growth of all kinds was formerly considered the principal agency in the destruction or absorption of organic matter. It is now, however, extremely doubtful to what extent, if at all, vegetables can absorb the complex

organic substances contained in sewage, before these have been acted on by the nitro-bacteria. It is a well-known fact (Wiley, loc. cit. p. 79.) that lands, which, however suitable they may appear to be for agricultural purposes in other respects, for one reason or another are poorly supplied with these organisms, do not become fertile until this deficiency has been supplied. This is so even when the soil is rich in organic matter. An instance is the case of land which has been reclaimed from submergence with water: if ground is constantly under water, these organisms are of course deprived of the supply of oxygen necessary for their growth and activity, and gradually die out. Well, when such land is reclaimed, it does not become fertile till it has been turned over and exposed to the air several times, and until some time has elapsed. The reason is that time must be given for the inoculation of the soil with nitro-bacteria, and for their growth and development, as it is by their agency that the organic material in the soil can be made available for

plant food. This being so, it would appear that the growth of plants (or rather, of most kinds of plants) on a piece of ground treated in one way or another by the application of sewage can have little or no effect on the purification of the sewage. They simply absorb the products of that purification process, which are so soluble and innocuous that they may be easily and safely removed by the water of the sewage itself. It is not certain that this is true of all plants: it may be that some can directly absorb these complex organic compounds, or at any rate assist in breaking them down. Among these plants, to which the name "carnivorous" has been applied, are osiers, and ryegrass.

The living organisms which feed on and destroy effete organic matter may be thus summarised:—

1. Putrefactive Organisms, divided into aerobic and anaerobic.

2. Organisms which form ammonia and its compounds from organic substances, — possibly many of them identical with the aerobic forms of putre-

factive organisms

3. Organisms which convert ammonia into nitrous acid and nitrites. These can of course only affect complex organic matter which has been acted on by No 2. group.

4. Organisms which convert nitrous acid and nitrites into nitric acid & nitrates. These again must follow the action of the preceding group.

5. Infusoria.

6. Some few plants

These are Nature's scavengers; they together form her "cleansing department". Having considered them, and the conditions under which they work, let us now proceed to describe some of the methods which are followed in endeavouring to submit sewage to their action on a large scale. Until quite recently it was thought to be a "sine qua non" of success in sewage treatment to exclude the action of the anaerobic putrefactive organisms. We shall therefore leave the methods which employ these anaerobes to the last; they are not complete in

themselves as methods of purification; sewage which has been submitted to them must subsequently be treated by one or other of those other methods to be presently described, if an effluent of any considerable degree of purity be desired. Those other methods are,

(a.) Land Treatment
  1. Broad Irrigation
  2. Intermittent Downward Filtration
(b.) Artificial Filtration.

Application of Sewage to Land

As stated above, there are two ways in which this treatment of sewage by applying it to land may be carried out. One is by "Broad Irrigation" the other by "Intermittent Downward Filtration" The choice between the two is largely governed by the amount of land available, and its Nature.

Broad Irrigation :— In this method the object aimed at is to make the sewage pass slowly in a horizontal direction in the upper layers of the soil on which crops of various kinds are grown. The amount of sewage applied

to each part of the land, and the times of such application, are regulated by the needs and interests of these crops. It follows that the area of land required is large compared to the volume of sewage to be dealt with. In order that the sewage may pass in the direction desired, it is necessary that the land employed should have a gentle slope. It is applied at the upper part of the slope, sinks into the surface, and flows gently down in the interstices of the upper few inches of the soil till it reaches the bottom. What the best gradient for this slope is, so that the sewage shall neither pass too rapidly through or over the surface, nor pass too slowly and stagnate, depends chiefly on the nature of the soil. If it be very open and pervious a steeper gradient is required, for if the surface be too flat, all the sewage will sink in at the upper part, and the lower part will be starved; while from the point of view of the purification of the sewage, the latter will only have been subjected to the action of nitro-bacteria in a small part of the area, instead of to that of those in the whole area.

On the other hand should the ground be very impervious in its character, the slope must be more gentle, because it takes longer to sink in, and the tendency to run over the top, without coming into actual contact with the soil at all, is greater. The slopes vary from 1 in 20 to 1 in 120 (Prof. Robinson, "Sewerage and Sewage Disposal" page 51.). In this connection it may be stated that dense clay land may be made much more permeable and therefore more suitable for the treatment of sewage by appropriate preparation. This consists in deeply ploughing the surface to the depth of about nine inches, then spreading over it a thick coating of screened ashes. This has the effect of opening up the soil (Santo Crimp op. cit. p. 124.)

A variety of means for the distribution of the the sewage is employed, different methods being used according to the contour of the ground. If the ground be flat and heavy it should be laid out on the ridge and furrow system, the ridges being about 33 feet apart; a fall is given to the furrows longitudinally. The carrier, a simple grip, is cut along the ridge and

the sewage diverted down each side by means of stops. If the ground have natural slopes or ridges, the carriers are conducted along the upper parts of these and the sewage is diverted as before. The main permanent carriers should be constructed of some durable material at such a level that they can be completely emptied.

Drainage :- If the land is pervious, a few ordinary agricultural drains at suitable intervals and depths are all that is required. If it is impervious a difficulty occurs, especially with clay soils. In dry weather they have a great tendency to crack; when sewage is applied after a spell of drought, it will run down the first crack it comes to. If it finds a drain handy at the bottom of the crack, it flows off having eluded treatment altogether. The best way to avoid this is to place the drains under divisions between the plots to which sewage is applied, or under roads, so that they encircle rather than pass under each plot. The surface should also be treated as mentioned above.

To ensure success the sewage should be

applied in as fresh a state as possible, because otherwise it may cause a nuisance from its offensiveness; besides when fresh it has lost little of the ammonia which is its most valuable manurial constituent. Then the question arises as to whether the solids should first be removed from it or not. If the soil be very pervious, perhaps all but the very large particles may be allowed to pass onto the land. If the soil be stiff and impervious then it becomes necessary to remove as much of the suspended solid matter as possible, before the sewage is distributed over the land. This may be accomplished by one or other of the mechanical straining methods mentioned above (when the solid matter so obtained may be disposed of by digging it into the ground), by chemical precipitation, or by one of the bacteriological processes for liquefying the solids to be described later.

Another great aid to the purification of the sewage and to the growth of the crops is the free application of lime to the land. The reason for this we have already seen in the description of the conditions under which the nitro-bacteria work. In

some kinds of soil from their chemical composition it may not be so necessary as in others.

The quantity of sewage which can be disposed of by broad irrigation is probably not more than 20,000 gallons per acre per day, We cannot go on applying this quantity for anything like the whole year round. In this country the unit of 100 persons per acre has been adopted for broad irrigation, but where the interests of the crops are first consulted, probably 30 to 50 persons would be near it (W.S. Crimp. op. cit. page 128.)

Crops. — Where the volume of sewage is small in comparison to the acreage, all ordinary crops may be grown: where it is large, they must be restricted to rye-grass, mangolds, osiers, and some other plants, which have been found to thrive well under large doses of sewage, and being able to endure the excessive moisture.

Intermittent Downward Filtration differs from the preceding method in that the land required is not so great in extent, but it must be of a suitable nature for allowing moderately large

quantities of sewage to pass through it in a downward direction; it must be porous. It is laid out in a number of level plots. The sewage being applied to one or more of those plots, while the others are resting, passes down vertically through the interstices of the soil for four, five, or six feet, and then is received into drains prepared for it. The essential part of the process is that each plot should be allowed ample time in the twenty-four hours to rest and get thoroughly aerated. If the ground is very porous, and the sewage is applied in small quantities at a time, the plots may advantageously be laid out in ridges and furrows, the sewage being directed down each furrow in succession. By this means uniform application is better secured, while vegetables can be grown on the ridges, the sewage rising to them by capillary attraction. Except in this case the crops grown on the plots must be limited to rye-grass, osiers, and a few other plants which will thrive under like conditions.

In the laying out of land for sewage purification, by whatever method, great care must be taken that the surface

soil is first removed before any levelling or ridging is done, and that it is as carefully and evenly replaced after these operations are completed. The necessity for this precaution is obvious after what has been said regarding the habitats of the micro-organisms. The first laboratory experiments to throw light on the purification of sewage, ~~were~~ by this system of filtration, were published in the first report (1870) of the Rivers Pollution Commissioners. They were made by placing the soil to be experimented on in a glass cylinder about 6 feet long placed vertically, and allowing the sewage to pass down through it. It was in these experiments that the difference in the purifying powers of soils was discovered. The Commissioners estimated that one acre of land would suffice for the purification of the sewage of 2000 persons; but it has been found that this is as a rule too high an estimate, 1000 persons to the acre is now the basis of calculation.

Where this method of applying sewage to land is adopted, the purification of the sewage is the first object, the crops are of secondary consideration

Attificial Filtration

It will be remembered that in speaking of the life conditions of the organisms concerned in the oxidation of the organic matter in sewage, it was stated that they were greatly aided in their work by the provision of some form of "scaffolding", on which they could carry out their duties in the body of fluid. Such a scaffolding has been described under the last two methods spoken of: it was provided by the soil. Now artificial filtration is simply an attempt to produce an artificial soil, which shall possess the best possible qualifications for acting as such a "scaffolding". The principles involved in the process are then the same as in land treatment.

Artificially constructed filters have been employed in the treatment of sewage almost since attempts were first made to deal with the problem of sewage disposal. They were constructed of many different materials, of which perhaps ashes and sand were the favourites. Till quite recently they all proved failures for two reasons principally, namely, they were

usually quite inadequate in size for the work required of them, and the principles and modus operandi, which must be looked to if success is to be attained, were not at all understood. The action sought to be brought about by the use of these filters was a simple mechanical straining of the sewage through a material of such fine porosity that all suspended matters should be left on the filter and thus separated from the liquid. This action certainly occurred, but the very success of the plan (so far) defeated the ultimate object, namely, the purification of the sewage. The solids left on the filter rapidly decomposed, so that, if they did not actually choke the filter by their accumulation and so prevent any sewage passing at all, they prevented any purification taking place. The products of decomposition being added to whatever liquid passed through, the effluent often issued from such a filter in a worse condition than that in which the sewage had entered it. The evil might have been largely reduced had the filters been only occasionally aerated, but they were so few in number and so

small in area, that they were used continuously, until sooner or later the whole filtering medium had to be removed and then the process was gone over again. Curiously enough plans of arresting the solids and submitting them to putrefactive decomposition have been used with success during the last few years, but under different conditions and restrictions, as we shall see later. The only method of filtration of sewage which, till recently, gave satisfactory results was that in which a natural filter, namely, land, was employed. As stated before, the chief reason for this was that in studying the requirements of the crops grown upon the land, the "filter" was given a chance of carrying out its work of purification. It will of course be evident from what has been already stated that the so-called "filtration" of sewage is only to a very slight extent a true filtration. It is more properly a fermentation process.

Experiments on the Filtration of Sewage

The experiments already referred to as being published in the Report of the

Rivers Pollution Commissioners were made, of course, before the true character of the process was recognised.

Massachusetts Experiments. — As in the case of the chemical treatment of sewage, so in that of filtration, a great deal of information has been gathered from the experiments conducted by the Massachusetts Board of Health. They were carried on at St. Lawrence in the years 1888 to 1893. The apparatus employed consisted of circular tanks about 14 feet in diameter, so that their area was exactly $\frac{1}{200}$th of an acre; they were six feet deep and puddled so as to be water-tight. In each an under-drain of horse-shoe section was placed with the open part downwards, and half an inch above the bottom, resting on blocks six inches apart. The floor of the tanks was covered with gravel in layers of various sizes, the bottom layer consisting of stones about 1 inch by 2 ins; the gravel forming the layers above this gradually diminished in size till the diameter of the particles in the top layer was about one-eighth of an inch. This fine gravel was covered with a layer of very coarse mortar sand, three and a half

inches deep in the middle of the tank. the total depth of gravel was also three and a half inches. This substratum was the same in all the tanks. In each tank, over this substratum, was placed the special material to be experimented on. These were as follows:-
No 1. tank had placed in it, over the substratum described above, five feet of very coarse clean mortar sand;
No 2. five feet of very fine nearly white sand;
No. 3. four feet of peat with one foot of the layer originally covering the peat;
No. 4. five feet of river silt, mostly very fine sand;
No. 5. five feet of good brown soil from a well cultivated garden;
No. 6. 3 ft 8 in. of coarse and fine sand and fine gravel;
No. 7. Same as No. 6., above which were placed 10 inches of yellow sandy loam and 6 inches of brown soil;
No. 8. Same as No. 6. above which were placed 8 inches of yellow sandy loam, and above that again, 8 inches of similar sand and gravel to that beneath.
No. 9. 4 ft 3 inches of very compact sandy hard pan of clay, sand and gravel cemented

with 9 inches of brown soil.
Besides these tanks, ten smaller ones of galvanized iron were used under cover. Their area was one-hundredth of that of the larger tanks, and they were filled with somewhat similar materials.
The sewage passed through these tanks was ordinary American city sewage, which is more dilute than that in this country.
The test applied to the working of the filters was comparison of the nitrogen in the organic matter of the sewage with that issuing in the effluent as ammonia and nitrates. The nearer the nitrogen of the nitrates in the effluent approaches the whole amount of nitrogen in the sewage the more complete is the purification.
The sewage was applied at various rates each day except Sundays — a double dose being applied on Saturdays.
The first thing established in these experiments was that nitrification does not begin until the temperature of the effluent from the tank is as high as 39° F, but having once been started, nitrification goes on, although the temperature of the effluent falls below 39°: even as low as 33°, though the pro-

cess is not nearly so complete at these lower temperatures. The process was found to be very successful in removing the organic matter – as much as 90 per cent being removed from the sewage in some cases. As regards bacteria, it was quite as successful, usually less than 1 per cent of the bacteria in the sewage being found in the effluent. The coarser materials allowed more to pass than the finer. Peat and garden soil stopped practically all.

A bed of washed gravel stones was also employed in these experiments for filtering sewage through; it was 5 feet deep. Sewage was applied to it for nine months nine times a day (at intervals of an hour) for six days in the week, in quantity equal to 81,400 gallons per acre per day (or to 70,000 gallons per acre per day all the year). The result was that 98.6 per cent of the organic matter in the sewage was converted into nitrates, and more than 99 per cent of the bacteria were removed. The quantity was then increased by applying the same amount hourly for fourteen hours instead of nine. This was equal to 126,000

gallons per acre per day for 6 days in the week. The result was the conversion of 98.5 per cent of the organic matter into nitrates and the removal of 99.6 per cent of the bacteria. The general results of all the experiments showed that peat, from its impervionsness to liquid, is quite unsuitable for intermittent filtration: it also is very retentive of liquid, thus interfering with the aeration so essential to success. The other materials employed were all successful when the quantity applied was adapted to the capability of each. Fine soils and sands produced excellent results, but at a very slow rate, on account of the time the liquid takes to pass through them, and the time which they require for rest and aeration. On them, too, surface clogging is apt to occur and must be guarded against, either by frequent removal, and replacement by fresh material, of the upper layers, or by prolonged periods of rest. It was found that filters composed of fine material throughout their whole depth, or even the greater part of it, soon became useless. The lives of the others seemed practically un-

limited. The nitrification proceeded most briskly from the end of April, through May, and June.

Mr. W. J. Dibdin's Experiments. — Mr. Dibdin, chemist to the London County Council, made a series of experiments on filtration of the effluent from the chemical precipitation tanks at Barking. The details and results of these experiments are published in a report to the London County Council dated October, 1895 (reprinted, Jan^{y}. 1896.)

He made two series of experiments: one conducted with small tanks constructed of wood, and each equal in area to $\frac{1}{200}$th of an acre; each was filled with a different material: the other series was conducted with one large filter measuring one acre in area, and composed of coke breeze.

The following are some of the details and results of these experiments.

Series I. All the tanks in this series, (four in number) "were worked at the same rates and during the same hours. During the first six weeks sewage effluent was passed through at the rate of 500 gallons per square yard per day.

"whilst from the middle of July to the end of August the rate was reduced to one-half or 250 gallons per square yard in 24 hours. The filtration was intermittently continuous, the filters passing effluent constantly for 8 hours daily and resting during the remaining 16 hours, being allowed to run dry at the end of each day's work. The outlet valve was closed just sufficiently to keep the filters full, the effluent being level with the surface of the filter material." The average rate at which the sewage was passed through these tank-filters was, inclusive of rest periods, 411,000 gallons per acre per 24 hours. The filtrate and the effluent were frequently sampled and analysed, great care being taken that the two sets of samples corresponded.

Filter No 1. This filter was filled with burnt clay ballast to the depth of four feet, the larger pieces being laid at the bottom and the remaining unsifted portions being placed above. The effluent from the chemical tanks was passed through it in the manner described above. The result was that 43.1 per cent

of purification was effected as measured by the oxygen absorbed in 4 hours, 50 per cent as measured by the albuminoid ammonia. Clarification was not well attained compared with that in some of the other filters. No alteration or renovation of materials was required, all that needed to be done was the filling up of some subsidence holes which formed on the surface.

Filter No 2. This filter was filled with Lowestoft shingle of pea-size. The clarification effected was 45 per cent greater than in the case of Filter No 1. The purification as measured by the oxygen absorbed averaged 52·3 per cent, by the albuminoid ammonia, 43·1 per cent. This filter also required no attention.

Filter No. 3. Four feet of coke-breeze, covered by 3 inches of gravel to prevent the coke from floating, formed the material used in this filter. The clarification was the same as that effected by filter No 1. The purification was 62·2 per cent according to the oxygen absorbed, while 60·4 per cent of albuminoid ammonia was removed. All the attention required consisted of the filling up of holes.

Filters Nos 4 & 5 formed together one compound filter; they together equalled in area each of the others, and the sewage effluent passed through the two at the same rate as it passed through the rest. Each filter No 4. measured $\frac{1}{300}$th of an acre and contained, from below upwards,

gravel, walnut size	3 inches
gravel, bean size	2½ inches
gravel, pea size	1½ inches
Sand	10 inches

The effluent passed through half as fast again as it did through filters 1. 2 and 3.; the clarification effected was much greater than in them. The purification amounted to 46.6 per cent in the average oxygen absorbed, and 50.8 per cent in the albuminoid ammonia. Twice the filtrate became slightly putrid, an event which never happened with any of the other filters. The surface had to be repeatedly raked and cleared, whilst 2½ inches of the sand were removed and replaced by fresh material on one occasion.

Filter No 5 contained from below upwards.-

gravel, walnut size,	3 inches
gravel bean size,	2 inches

Gravel, pea size,	1½ inches
Sand	1 inch
Polarite	12 inches.

It had an area of $\frac{1}{600}^{th}$ of an acre. It possessed perforated pipes leading to the surface to aid in aeration. The effluent from filter no. 4. was passed through it so that its rate of passage through the combined filter was brought up to the level of that through the first three filters. The clarification effected was better than that produced by any of the other filters. The purification amounted to 61.6 per cent in the oxygen consumed, and 60.1 per cent in albuminoid ammonia removed (by the passage of the effluent through both parts of the combined filter)

In summing up the results of these experiments, Mr. Dibdin gives the following table of the clarification effected by each of the filters. The figures are units of depth required to obscure a standard mark.

Filter No 1	Burnt Ballast	1
Filter No 3	Coke Breeze	1
Filter No 2	Pea. shingle	1¾
Filters No. 4 & 5	Compound	2½

Of the last, 2¼ is due to the first part of the combined filter, and ¼ to the second.

Mr. Dibdin concludes that sand is too fine a material for sewage treatment, and that the burnt ballast was too coarse. Burnt ballast and gravel may be made much more efficient by using a greater depth of more finely granulated material and filtering at a slower rate. Coke gave the best results. Polarite produces an effluent which only excels that from coke in appearance, while its power is prohibitory. He attaches very little importance to the relative numbers of bacteria in the filtrate; he regards their presence as an evidence of the activity of the filter. They can be removed by using finer materials.

Series II. This series of experiments was made on a filter one acre in area. The ground was first levelled and embanked where necessary; perforated drains were laid to provide for emptying. The material consisted of three feet of coke covered with three inches of gravel. The first thing done was to pass large quantities of sewage-effluent through without regard to results, the liquid sometimes standing 6 inches above the level of the filtering material. After

six weeks all the filtrates were putrid. The daily quantity that could be passed fell rapidly till at the end of twelve weeks the filter was quite useless, being putrid throughout. This showed the necessity for rest and aeration.

The surface was now raked over, and the filter allowed to rest for 3½ months; for 3 months of that time it remained putrid, but during the last fortnight the coke was quite sweet.

The next thing done was to fill and empty the filter twice daily with a view to getting it into good biological working order. The purification effected gradually rose. The quantity passed through the filter was gradually raised from 500,000 gallons per diem, till it reached 1 1/6th million gallons daily for six days in the week. The method adopted was to fill the filter level with the surface as quickly as possible, let it stand for one hour, then empty as quickly as possible. One hour was allowed to elapse before again filling it. The effect was very satisfactory and the purification amounted to an average of 98 per cent. No signs of deterioration

appeared. It worked well during severe frost. Mr. Dibdin concludes that, especially if clarified by chemical precipitation to begin with, sewage may be purified to any desired degree by this method, the degree of purification depending on (1.) the length of time during which it is allowed to remain in contact with the filter, and (2) the length of time allowed for aeration. "If a reduction of 75 per cent in the oxidizable matters in solution be considered as sufficient, the quantity that can be treated per diem on an acre of coke breeze is one million gallons ---- This rate is probably the highest that can be worked under all conditions of seasons."

Lowcock's Experiments. (Prof. H. Robinson, op. cit. pages 142 et seq.) In these experiments the plan was adopted of forcing air into the filter while filled with sewage. The tank used was 4 ft 6 in. square, and 4 feet deep. At the bottom were placed 3-inch open-jointed agricultural drains covered with a 6-inch layer of broken stones. On this layer were 15 inches of stiff clay mixed with engine ashes and building sand in the proportion of two

parts soil to one each of the others. Into the rough stone was introduced a 3-inch perforated pipe through which air was forced from a compressor. Crude sewage after being roughly screened was applied continuously to the filter – the air being at the same time continuously forced in. The sewage was applied at the rate of 263,780 gallons per acre per 24 hours for 19 days, the effluent being clear and colourless, and after a few days odourless. A deposit 5 inches deep then covered the filter, which was raked over and again started at the same rate as before. After 14 days, analysis showed a reduction of 99 per cent in the albuminoid ammonia. In a further 14 days the surface became choked and the daily amount of sewage was reduced to 66,900 gallons per acre per day; the character of the effluent remained good. Then the working was stopped and the top 2 inches removed and replaced by fresh material; the application of sewage was then resumed at the first rate. Good results were obtained in the use of this filter for improving effluents from precipitation tanks, in which sewage had first been clarified by the ad-

dition of 6 grains of lime and 12 grains of Spence's alum per gallon.
Another experiment was made with the tank filled differently :- first 6 inches of stone broken to pass through a 1 inch mesh laid over the drain-pipes, then 3 inches of stone broken to pass through a $\frac{5}{8}$th inch mesh, then 10½ inches of stone broken to pass through a sieve having 70 meshes to the square inch. Over all was placed 3 inches of building sand. This filter soon choked at the surface but remained quite sweet and clean below, with an earthy smell.
His experiments with these tanks led Mr. Lowcock to finally adopt a filter made up as follows from below upwards :-
(1.) 12 inches of pebbles containing drains
(2.) 6 inches bean-sized gravel
(3) 2 ft 6 in. pea-sized gravel
(4.) 12 inches pebbles, containing air-blowers.
(5.) 4½ inches bean-sized gravel
(6.) 4½ inches pea-sized gravel
(7.) 9 inches of sand.
The surface is divided into small areas by divisions extending only a short way below the layer of sand, so that the sewage may be diverted for cleansing purposes without interrupting the flow.

Having described the principal experiments which have been made on the various methods of submitting the organic matter contained in sewage to the action of nitrifying organisms, let us see what conclusions may be drawn from them regarding the construction and ~~de~~working of artificial filters.

(1.) The action of these filters is twofold, namely, (a) mechanical arrest of matters in suspension, and (b) destruction and conversion to innocuous substances of organic matter in solution. Now it seems clear that while we wish as much of the latter action to take place as possible, the former must be limited in extent, or it will interfere with the success of the whole. The desideratum in a filter is porosity; if therefore too much arrest of suspended matter take place the value of this porosity is destroyed. The arrest naturally takes place chiefly at the surface: it tends to choke the pores near the surface, and thus prevents the aeration of the deeper layers when the filter is emptied. With the deficiency in the supply of oxygen to the deeper layers, the nitrifying organisms lose their activity, the anaerobic organisms

of putrefaction sets in, and the filtrate becomes putrid. If then the natural aeration taking place when the filter is emptied is to be relied on, if no special means are to be taken to force air into the body of the filter, it is necessary to remove from the sewage as much of the suspended matter as possible, before submitting it to the action of such a filter. This may be accomplished by straining the sewage through a stationary grid, or some form of rotary screen, or by chemical precipitation, or by bringing the solids into solution through the action of liquefying organisms in the manner to be described later. Removal of the solids, at least the grosser of them, is the first essential to success in artificial filtration. The fact that the mechanical action of the filter must be kept within limits has an important bearing on (2.) the Selection of a Filtering medium. The best material is that which will (in a given time) render the largest quantity of sewage tolerably clear, inodorous, colourless, and not liable to putrescence.

Some of the chief materials which have been experimented with will now be considered a little in detail as to their qualifications.

1. Peat has been found capable of ac-

giving considerable nitrifying powers. It is, however, quite unsuitable for use in a filter on account of its behaviour towards water. Water takes a long time to pass into it and through it. When once saturated it is very unwilling to part with the water, it retains a large quantity in its interstices. Obviously these must be great dis-advantages, for much time would be wasted in bringing the fluid to be treated into thorough contact with the material of the filter, and the aeration would be seriously interfered with by the retention of water. Accordingly the quantity of sewage capable of being satisfactorily dealt with in a given time by a peat filter must be very small.

2. Soil, especially if taken from the surface of land which has been well cultivated and manured, is one of the most efficient materials for sewage purification, if no regard is had to the time occupied, or the quantity passed. (Here it should be mentioned that these finer materials, like soil and sand, must never be employed for the construction of the whole depth of a filter, or it will speedily become useless; they can only be used for the upper few inches.) Soil of the nature

described will act efficiently from the very first: it will remove practically all the organic matter, as such, and all microbes. If no bacteria are present in a filtrate, it seems to me to suggest that the filter through which it has passed is not bacteriologically active in its lower depths; that the lower depths are not sufficiently aerated, because the surface layers are not porous enough. Accordingly we find that the quantity of sewage passed by a filter, on whose surface there is a layer of soil, is relatively small, and that surface choking is liable to occur. When this occurs the filter must either be rested, and the surface raked over and thoroughly exposed to the air, or the upper few inches of soil may be removed and replaced by fresh material.

3. Sand forms a very efficient material, but here too, the mechanical straining action is too much in evidence, just as in the case of soil. These materials are too fine for the rapid purification of foul waters.

4. Burnt Clay Ballast is often the most suitable material for the construction of a filter, because it is very efficient and may sometimes be more easily and cheaply ob-

tained than any other. If the filter is to be constructed on clayey land, the ballast may be made by burning the clay dug out in the preparation of the bed. It has the further advantage that it may be broken to just the right degree of fineness, so that the clarification effected may be as high as possible without producing a liability to surface clogging.

5. Gravel — also very suitable and efficient if the right sizes are selected, just as in breaking the ballast.

6. Shingle & Broken Stone have practically the same qualifications.

7. Coke. Mr. Dibdin found coke to be on the whole the most efficient material for the construction of an artificial filter, that is, it could bring the largest quantity of sewage to a required state of purity in a given time. I have no doubt that its efficiency is largely due to the porosity of the individual pieces as well as to the general porosity of the body of a filter constructed of it. Mr. Dibdin showed that such a filter could do more work if means were taken to ensure rapid filling. This of course was partly due to the time saved, but I think it might partly de-

fend on the fact that, when a coke filter is rapidly filled, the liquid will surround the individual pieces before all the air has time to escape from their pores. A good deal of air may thus be imprisoned and carried into the body of the liquid. This imprisoned air will escape slowly, and in doing so it must rise through the sewage which will dissolve and retain some of it. It must be of considerable value in aiding the nitrifying organisms in their life and work. On the other hand if the filter be slowly filled, the liquid as it rises will force the air out of the pores of the individual pieces in front of it. The clarification effected by coke is not so great as that effected by finer materials. A layer of gravel must be placed on the surface of the coke to prevent its floating.

8. "Polarite" seems to possess no properties enabling it to purify sewage beyond its physical characteristics. It is used in conjunction with sand and gravel which account for a good deal of the purification. It seems to be costly: cheaper materials can be got to act as well.

(3.) Arrangements for filling and emptying. We have already seen the advantages

of rapid filling in the case of a coke filter: they are also great in those made of other materials, on account of the saving of time effected. The power of a filter largely depends on the efficiency of these arrangements. The emptying is usually accomplished by means of perforated, open-jointed agricultural drains laid in the lowest layer. They should be ample in number and size. The rapid filling and emptying may be greatly facilitated by having a number of small filters rather than one large one. Emptying has been further aided by pumping arrangements, but these must always add to the cost.

(4.) Method of working the filter. Experience has shown that in starting a newly constructed filter a little care is required to get it into good biological condition. If soil from well cultivated and manured land be the material employed, then the filter may be efficient from the beginning. If on the other hand coke, ballast, gravel, or broken stone be used, it can contain very few, if any, nitrifying organisms. These must be brought to it by the sewage, and they must be given time to accumulate and multiply

in their new home, which they do rapidly. The best way to attain this object, or "seed" the filter is simply to fill it with sewage, and empty it once or twice daily for a week or two.

Having got the filter into good working order, thoroughly impregnated with the necessary bacteria, the best way of working it seems to be to fill it as quickly as possible, allow it to remain full for one hour at least, rapidly empty it, and allow it to remain empty for one hour at least. Besides this, it should have one full day's rest in the week. In filling, the sewage should never be allowed to rise above the material of the filter, because, as we saw, light prejudicially affects the organisms, and hence the sewage standing above the surface of the filter is apt to remain unpurified.

Treated in this way a filter will practically go on purifying sewage for ever, and will require very little attention and no renewal of material.

Dundrum Tanks

Before proceeding to consider the processes which have been devised for bringing the solid contents of sewage into solution by the action of bacteria, it is necessary to mention a method in which the oxidising organisms are supplied with oxygen, not by means of aeration, but by adding to the sewage chemical substances which are easily decomposed, and in the process give off free oxygen. Such a method has been devised by Messrs Adeney and Parry, and is used in treating the sewage of Dundrum Asylum. The apparatus consists of a series of three tanks, each 4 feet square by 16 feet deep. After being strained, the sewage is admitted to the first of these tanks and is spread evenly over the bottom: it has nothing added to it. As the tank gradually fills the suspended particles, not previously removed by straining, are caught in the gelatinous matter, and fall to the bottom. The rising sewage is partially filtered through the falling precipitate (a similar action to that employed in the Kniebühler tanks on the Röckner-Rothe system.) From

this tank the sewage passes through a mixing race, in which it has 2 to 5 grains of manganate of soda per gallon added to it, to the second tank. The manganate of soda is here reduced by the sewage to the brown oxide of manganese, and falls to the bottom carrying more solid particles with it. From the second tank the sewage passes to the third, where 2 or 3 grains per gallon of nitre are added. Here, the micro-organisms furnished with oxygen by the nitre, break up the organic matter without putrefaction or nuisance.

The tanks are filled and emptied once in the twenty-four hours.

The sludge is drawn from the first tank, strained through canvas sacks, and spread over the floor of a drying shed: a little of the manganese from the second tank is added, and the two are worked up into a manure. (Prof. Robinson op. cit. p. 141.)

Liquefying Processes

It will be remembered that in speaking of the organisms of putrefaction we found them to be divided into two classes, the aerobes and the anaerobes, and that it was the action of the latter, which it was the aim of most systems of sewage disposal to prevent, because they produced offensive substances, which give to putrefaction its characters. Recently it has been found that, if carefully planned and controlled, the action of these organisms can be utilised with great benefit for the destruction of Sewage, because some of the principal of them have the faculty of liquefying or liquefying solid organic substances. The advantage of this is obvious, for if we can dissolve the organic solids in sewage, then the whole of it can be brought under the influence of the nitrifying organisms, and can consequently be purified, if sufficient aeration be provided, and long enough contact be allowed. In that case there will be no sludge to trouble and cause expence, even no strained solids to get rid of. The whole of the sewage will have been thoroughly disposed of.

Scott-Moncrieff Process

This process is described in a report upon the system by Dr. R. C. Houston (published by Waterlow, Bros. & Layton). The principle involved in it is that it is wrong to remove the solids from sewage by preliminary straining, because they are thereby removed from the conditions most favourable to their speedy destruction. It is of course impossible to do otherwise than remove them, if the sewage be applied in its crude state to a filter worked on the downward filtration principle, since in that case gravity favours choking. If, on the other hand, the sewage be passed through a filter worked on the upward principle, gravity will have the opposite tendency; it will prevent choking. If it be desired that such a filter should be active biologically, it is necessary to ensure the constant removal of the products of such action, for the products, when they remain, are fatal to the life and activity of the organisms. The filter then must be so constructed, that the whole of the sewage shall be constantly on the move, shall be constantly changed; there must be no residual spaces where the products of

the bacteriological action can accumulate, and interfere with its own continuity. If liquefying organisms be grown on a solid medium in a test-tube, they grow, thrive, and work away for a time, but sooner or later the process slows and gradually ceases; the organisms are poisoned by their own products. The removal, then, of these products is essential to success; it is attained by restricting the inlet, constructing the inner surfaces of the tank used of smooth materials, sloping and curving them properly, and thus ensuring that the whole of the contents shall be continuously in motion.

The filter in the Scott-Moncrieff process is of an elongated form, and about three feet deep: at the bottom there is a restricting chamber, covered with a metal grating, into one end of which the sewage is admitted. It passes along the restricting chamber, through the grating, and up through the gravel, flint, or coke, which lies upon the grating, and forms the material of the filter. The effluent flows away from the top. When solids come up to the grating covered by the filtering material, they of course cannot get any farther; they fall back to the

bottom, where they remain under the influence of the liquefying organisms till they are dissolved. At the same time the products of their dissolution are constantly being removed from the scene of action by the continuous stream of fresh sewage. The process of liquefaction under these circumstances seems to be very rapidly accomplished; when the filter is emptied and the restricting chamber cleared out, all the solids found are those brought by the last day or two's sewage. The apparatus is worked continuously; therefore the only oxygen available for the use of the microbes is that contained in the sewage; there cannot therefore be any great amount of nitrification. The process must only be regarded as one preliminary either to treatment by land, or to artificial filtration on the intermittent downward principle. Although the process is to a large extent an anaerobic one, it has been found very beneficial to rest and aerate the filter periodically. With this end in view they are now constructed in duplicate, and each half is worked alternately. That rest and aeration should be of advantage is not sur-

fruing. since the chief liquefying organisms are not obligatory anaerobes but facultative anaerobes, that is, while they can work and live without oxygen, they flourish best in its presence.

Mr. Scott-Moncrieff claims that this process gets rid of the solids by a biological and natural agency, and that the effluent must therefore be in a state more favourable to a second natural process than if they were dealt with in any other way, which means that the effluent thus obtained is eminently suitable for application to land or to a filter.

In practice the process seems to work very well - the filter although unaerated does not give off offensive gases. The solids dis-appear, all that is left to represent them being a thick, black, and very offensive liquid, which is found in the restricting chamber. On cleaning the latter out, this liquid may be disposed of by applying it to the ground, which readily absorbs it. The effluent is of alkaline reaction and has an unpleasant smell; it may have some flocculent material floating in it.

The material used in the filter may be

flints, broken stones, coke, or gravel – anything in fact which will supply the requisite amount of surface, the operating tables for the micro-organisms.

The same thing is noticed in these filters as in the artificial filters previously described, namely, the necessity for getting a newly constructed filter "seeded", getting it into biological working order. Passing sewage through will accomplish this in time; adding some material which has already been in use will hasten the process. The fatty matter ought to be removed from the sewage before it is passed through the filter.

As to the exact degree of purification effected by these "cultivation-filters" it is not easy to form an opinion from Dr. Houston's report. He only gives analyses of the effluent, and none of the corresponding crude sewage, so that it is impossible to tell how much (if any) organic matter is actually destroyed.

It seems clear however, that the solids are liquefied by the action of putrefactive organisms, and that being so the process preliminary to nitrification must be at least partly accomplished, and the

effluent to that extent prepared for the further process. The fact of the sewage having undergone putrefaction does not seem to interfere with the subsequent nitrification of the organic matter. Putrefaction is stopped, and the putrefactive organisms largely removed from the effluent by simple aeration. Mr. Scott-Moncrieff allowed the effluent to flow down a "nitrifying channel" (half channel pipes filled with coke) of 30 to 80 feet in length with the object of aerating it, and encouraging the growth and action of nitro-bacteria. He was partly successful: had he adopted a more efficient method he might have been wholly successful in removing the putrefactive organisms from, and nitrifying the organic matter in the effluent.

The following liquefying organisms were isolated from the effluent from the filter-bed by Dr Houston: — Bacillus Fluorescens Liquefaciens, Bacillus Subtilis, Proteus Vulgaris, Bacillus Luteus, Bacillus Mycoides, Cladothrix Dichotoma.

By the time the effluent reached the bottom of the "nitrifying channel" these forms were greatly reduced in number.

The Septic Tank System

The Septic Tank system was devised by Mr. Donald Cameron, City Surveyor of Exeter, for the treatment of crude sewage by bacteriological means. He describes the process in a paper read at the Congress of the British Institute of Public Health at Glasgow, August 1896 :—

"The septic Tank itself is merely a receptacle designed to favour the multiplication of micro-organisms, and bring the whole of the sewage under their influence. To this end the tank is of ample size though not larger than would be necessary with chemical precipitation, and covered so as to exclude light, and as far as possible air. The in-coming sewage is delivered below the water level: and the outlet also is submerged, with the twofold object of trapping out air and avoiding disturbance of the upper part of the contents of the tank. On entering the still water of the tank the solids suspended in the sewage are to a great extent disengaged, going either to the surface or to the bottom according to their specific gravity. In the absence of light and air the organisms originally present in the

"Sewage increase enormously, and rapidly attack all the organic matter. By their action the more complex organic substances are converted into simpler compounds, and these in turn are reduced to still simpler forms, the ultimate products of the decomposition in the tank being water, ammonia, and carbonic acid and other gases. Other nitrogenous compounds may also be present, but they will all be soluble in a slightly alkaline solution – a condition which obtains with every normal sewage.

"No sludge is found. Examination of the bottom of a tank which has been in use for six months reveals only a thin layer of black earthy matter – the burnt out ash of the solids of the sewage, together with the mud and grit brought down by storm water. So far as accumulation at the bottom is concerned, it would seem that a tank may be used for an indefinite time without requiring to be cleared. The larger part of the solids in the tank are found at the top, where a somewhat tenacious scum soon forms, consisting of the lighter solids in process of decomposition. The intensity of the action going on is evidenced by the

"large bubbles of gas, which everywhere break through the scum. Here is probably the chief seat of the bacteriological action by which the solids are eventually thrown into solution. As soon as most of the organic matter in a solid substance is dissolved, the ash falls to the bottom, where decomposition continues its work. Presently a bubble of gas is formed, which buoys a fragment of ash and brings it again to the underside of the scum. The bubble soon becomes disengaged, and the ash falls again to the bottom. There is thus a constant interchange between the upper and lower layers of the tank, whereby its solid contents are brought under the most favourable conditions for rapid decomposition and solution. After a tank has been a short time at work the scum increases in thickness very slowly. In one case after thirteen months' work, the scum was only a few inches thick

"The effluent from the tank is comparatively clear and inoffensive, and not liable to any after fermentation, the work of decomposition being already done. In this state there can be no reasonable

"objection to its discharge into tidal water. It is eminently fitted for utilisation on land, containing as it does, all the constituents of the sewage having any manurial value, in a form immediately available as food for plants; while its freedom from suspended matter removes the difficulty met with in irrigation with crude sewage. It is also in a fit state for filtration."

The tank employed is rectangular, about three times as long as it is broad, and about seven or eight feet deep. The inlets, of which there are two, are situated at one end, the sewage passing first through grit chambers, over a submerged weir into the tank about midway between the top and bottom. The outlet is situated at the opposite end; it consists of a slotted pipe running right across the end of the tank, and placed about sixteen inches below the surface. By these arrangements the sewage is enabled to flow quietly into the tank, and the effluent to flow as quietly out, at points where the movement will be least likely to disturb the scum which gathers at the top, and the deposit which

collects at the bottom. Light and air are excluded by covering in the tank with a dome-shaped roof. The size of the tank is such that the sewage takes about 24 hours to pass through it, in other words its capacity must be equal to the whole amount of the daily sewage discharge. Probably a rather smaller tank than this would succeed in bringing the solids into solution; perhaps one of a capacity equal to two-thirds of the daily flow.

What is the effect of passing sewage through a tank arranged in this way?

1. Since the capacity of the tank is so large, the effluent must in the first place, apart from any chemical or vital action, be very much more constant in its composition than the sewage as delivered into the tank. Hence in any subsequent treatment, the difficulty does not occur of having at one time very strong, at another time very weak, sewage to deal with. It is very much more uniform in character after passing through a tank of this size.

2. A second action consists in the mechanical separation of the solids from the liquid. There is a deposition of the heavier solids at the bottom, and a rising of

the lighter solids to the surface. This must lead to a certain degree of clarification. It is easy to understand how, by these simple mechanical actions, the effluent should show some improvement on the state of the raw sewage.

(3) But it is claimed by the inventor that a further action takes place in the tank — that a rapid growth of micro-organisms occurs, that these attack the organic matter, particularly the solids, bringing them into solution. Now, how far is this borne out by chemical analysis of the sewage and effluent? In the Lancet, Dec^r. 5^th^. 1896, in an article on this system of sewage treatment, analyses by M^r. J. P. Perkins, Exeter, are given as follows:—

	Sewage	Effluent
Temperature	50° F	51° F
Alkalinity	35·5	25
Free Ammonia	3·8	2·2
Albuminoid N°	0·95	0·35
Organic Nitrogen	1·65	0·53
Oxygen absorbed in 4 hours	3·21	1·454
Chlorine	8·6	6·2
Nitrogen as Nitrates	—	mere traces
Total Solids	60·	46·

The samples from which these analyses were made were taken on the same

day, and it is quite evident that they are analyses of different sewages altogether, not of the one sewage before and after its passage through a process of purification. A glance at the amounts of chlorine shows us this, besides, if the albuminoid ammonia be reduced in a closed tank, we should expect the free ammonia to be increased.

It is of course difficult in a case like this to get samples of raw sewage and of effluent which can be profitably compared with some chance of learning what has taken place in the tank, and without falling into error on account of the varying composition of the sewage, except by taking the averages of long series of experiments. Probably the safest method is that adopted by Dr. Samuel Rideal in examining this system (Paper read before the Sanitary Institute, Dec^r. 9^th, 1896.). The tank capacity being approximately equal to the flow of sewage in 24 hours, it follows that sewage passing into the tank at a certain time one day, will leave it as effluent about the same time on the next day. Dr. Rideal's method was to take samples of sewage, propor-

tionate to the flow, every hour for 24 hours. From these, four "average samples" were obtained. Then beginning at the same time next day, hourly samples of the effluent were taken in the same way. The results of the analyses of these samples are stated by him as follows:—

"That the contents of the tank had been approximately changed is shown by the fact that the average chlorine content is practically the same in the raw sewage and effluent. In order to more clearly establish the difference between the sewage and the tank effluent, I have calculated the composition of the sewage to a constant chlorine content of 7 parts per 100,000. From the ascertained results, the changes produced by the passage of sewage through the tank may be summarized as follows:—

1. A marked increase in the total solids in solution or fine suspension.

2. A reduction of about 33 per cent of the organic matter as measured by the oxygen consumed.

3 An increase of about 33 per cent in free ammonia.

4. A reduction of about 45 per cent in the organic or albuminoid ammonia, or

50 per cent of the organic nitrogen.

5. A slight production of oxidised nitrogen and a dis-appearance of a small amount of the total nitrogen.

"It is therefore evident that the septic tank by means of its bacteria, enzymes, or spontaneous chemical decomposition, materially alters the composition of the raw sewage. The increase in the total solids in solution points to a solvent action of the water on matter in suspension, and this may be due to a digestive, or a purely physical process. But the marked dis-appearance of organic matter, and transference of the nitrogen from the organic condition to that of free ammonia is undoubtedly due to bacterial influences. The above changes should be capable of being confirmed by (1.) evidence of the production of gaseous carbon compounds, either oxidised as CO_2, or as hydrocarbons, and by (2) evidence of the production of nitrogen in a gaseous form, either as free nitrogen, lower oxides of nitrogen, or possibly ammonia which has escaped solution. This conclusion was confirmed by subsequent experiments which established the fact that the dissolved car-

"bonic acid was increased in the effluent, and carbonic acid gas, nitrogen, and marsh gas, and hydrogen, existed in the air in the upper part of the tank, which was also found entirely deprived of its oxygen. The raw sewage and the tank effluent were also proved to be devoid of dissolved oxygen, so that, although atmospheric oxygen can leak into the tank, I am of opinion that the amount of direct oxidation in the tank must be very small, and that the oxidised compounds produced must be formed from the dissolution, or the hydrolysis of oxygen contained in organic compounds."

It seems certain, then, that vital changes do take place in this tank, consisting of (1) liquefaction of the solids, and (2) breaking up of organic compounds into simpler forms, and that those changes are to a large extent the results of bacterial life under anaerobic conditions. They are therefore most likely due to the action of those organisms of putrefaction which liquefy gelatine (e.g. the Proteus forms), and which are facultative anaerobes. In a tank such as this they will have the field to themselves, they will encounter no

opposition from aerobes. The production of nitrites and nitrates in this form of tank is interesting; it tends to show that the periodic aeration found to be beneficial in the Scott-Moncrieff filter, is not so much required to provide oxygen to aerobic forms, as merely for the refreshing of the anaerobes.

The effluent from this "septic tank" requires some further treatment in the direction of oxidation or nitrification, by passing it over land, or through an artificial filter. When it leaves the tank means are taken to aerate it; it leaves so that it is spread out into a very thin sheet and made to fall through several feet of air. It is said that this aeration entirely removes the disagreeable smell it has on issuing from the tank. Now, in considering this "septic tank", the first thing that strikes one is that it is simply a modification of the cesspool. In what does it differ from an ordinary cesspool? In the latter also we have an apparatus for keeping back solids, which brings the sewage to a state of rest (to a certain extent at any rate), and from which light and air are often excluded. The differences are that in the "septic tank" arrangements are made (by size and shape)

which ensure that the sewage shall remain in it for a certain definite time, and shall not have much chance of escaping sooner or remaining much longer; arrangements are also made so that the entrance of sewage and the leaving of effluent shall cause as little disturbance as possible to the fluid already in the tank, and particularly to the surface scum and the deposit. In a cesspool, on the other hand, every time any sewage flows in, the whole surface is apt to be disturbed, and the sewage at the surface may stay a very short time in the cesspool; it may flow straight across from inlet to outlet in a few minutes, if a good deal of sewage happen to be discharged into the cesspool at any time. Again, the contents of the cesspool which lie near the bottom may not be changed or disturbed in any way for a very long time; they may only be changed by a process of diffusion. It seems to be the case, however, that solids do disappear to a very considerable extent in cesspools, and that on clearing them out only recent solids are found, the rest having been converted into a thick dark foul liquid. In the "septic tank" it is said that the principal action

takes place at the surface, below the thick layer of scum which forms. It seems likely that this may act as a sort of operating table for the organisms. They can have no such advantage as this in the ordinary cesspool; in the latter, too, the organisms working at the bottom, though they will be supplied with plenty fresh nourishment in the shape of solids of greater specific gravity than the sewage, must have considerable difficulty in getting away from their own poisonous products, and thus must be greatly hampered in the performance of their destructive duties. The organisms in a cesspool suffer from the disadvantages of the fluid at the surface moving too quickly, — so quickly and irregularly that they get no chance of erecting an operating table there —, and of the substances at the bottom changing too slowly.

The exclusion of light we have already seen to be necessary as it is prejudicial to microbic life. But why exclude air? Unless it be for the purpose of avoiding disturbance of the scum on the surface, the exclusion of air is not easy to understand.

The "Septic Tank" and Scott-Moncrieff System.

From the foregoing descriptions it will be

apparent that the two are similar in principle, in active agencies, and, so far as we can judge, in results. In the former, the scum which forms at the surface seems to act as a breeding ground for the organisms, just as the surfaces of the filter-material do in the latter. In the former again the separation of the solids, or rather their detention for further action by the micro-organisms is attained by the comparative stillness of the contents allowing the differences in ~~the~~ specific gravity to carry them to the surface or to the bottom as the case may be: in the latter, the interposition of the grating and the material covering it effects the same object. In both, constant and steady change of the fluid contents is aimed at.

Which of these systems may ultimately prove to be the better and more efficient in actual practice, it is difficult to say, but theoretically the Scott-Moncrieff process would seem to have the advantage for the following reasons:-

1. It seems to ensure the bringing into contact of ~~the~~ every drop of the sewage with the micro-organisms better than the "septic tank" system. It is just possible, however, that it may be better to limit the fluctu-

factive action to the solids ~~of~~ as far as we can, in which case this advantage would be minimised.

2. It provides for the periodic exposure of the micro-organisms to the air, and this has been found to increase their activity

The Removal of Micro-organisms from Sewage.

Hitherto we have almost entirely confined our attention to the removal of putrescible organic matter from the sewage in the course of its purification. It is necessary however to consider for a little the question of the desirability and the possibility of removing microbes during the process. We have found that by some of the bacteriological processes it is possible to produce almost any required degree of purification in sewage. To accomplish the complete removal of the organic matter or to convert it wholly into simple, stable and innocuous substances it would in all probability be necessary that the sewage should be submitted over and over again to the action of nitrifying organisms, be passed through land or an artificial filter two or three times. Now this repeated treatment would entail a very heavy outlay in the provision of the extra land, or filter capacity, an outlay which could hardly be looked for from the community. As much as we can expect is that the sewage should be so treated, that as much of the organic

matter as possible be converted into innocuous substances, and that what remains of the organic matter be in such a condition, that it is not liable to undergo putrefaction. With our present means, we cannot regard it as practicable to remove the whole of the organic matter from the effluent. Now, the small amount of organic matter left must be oxidised by Nature after the discharge of the effluent, and, as we have seen, Nature's method of oxidation is by the action of bacteria. Is it then desirable to remove these agents from the effluent before discharging it? Perhaps not. On the other hand, it is by no means certain that the whole of the organic matter in sewage forms suitable food for micro-organisms. Some may not, but if so it cannot be liable to putrefaction. There are other microbes often found in sewage whose destruction is one of the principal things to be aimed at in treating sewage. These are the pathogenic organisms. If it were possible to remove all the organic matter from sewage, then the removal of the micro-organisms also would perfect the process. Let us look at the various methods of disposal which have

been already described, and see what action they have as regards the bacteria.

1. Simple storage and settlement. This will remove some of the micro-organisms; they are carried down by the falling sediment. In a liquid like sewage, which contains so much food for them, they will rise again, or those left unprecipitated will multiply so rapidly, that there will soon be an increase in their original number.

2. Chemical Precipitation. – Much information as to the effects of the addition of chemicals to sewage on its bacterial contents was obtained in the Massachusetts experiments. According to Prof. Frankland ("Micro-organisms in Water" pp. 215, 216) the action of these chemical precipitants in removing bacteria is of three kinds.

(a.) That in which the precipitant is added in a solid and insoluble form, e.g. sand, china-clay, chalk, vegetable and animal charcoal, and coke. There is the greatest diversity in the bacterial purification effected by the substances belonging to this class, the more porous and slowly subsiding substances carrying with them a much larger proportion of the suspended bacteria than those which are smooth, in-

ferrous and therefore rapidly ~~slowly~~ subsiding.
(b.) That in which the precipitant is soluble and more or less chemically active, but in which through entering into reaction with constituents of the water, it is so rapidly converted into an insoluble form that little or no bactericidal effect can be exerted. Lime and alum in very small quantities act in this way. The precipitates in these cases, being actually generated within the water containing bacteria, are extremely successful in entangling the latter and dragging them to the bottom. The bulky alum precipitate acts better than the powdery lime precipitate.
(c) That in which the chemical added is soluble and produces a bactericidal effect in addition to the precipitating action.
In the Massachusetts experiments it was found that by using equal money values of chemicals the following percentages of the bacteria present in the sewage were removed.

Copperas and Lime	38.
Alum	91
Ferric oxide	92
Lime	93.

A particular proportion of lime gave the best results, while the larger the quantity of

the others used, the better results were obtained. It will be remembered that in speaking of the "Amines" process, it was stated on the authority of Dr. Klein and Mr. Cassall that the effluent was sterile, and that the precipitant was fatal to many pathogenic organisms.

3. Electrical Processes.— It is claimed for the Webster process that all the bacteria are destroyed. The Hermite process we have seen to be an efficient steriler of sewage provided that a solution of sufficient strength is employed, and that no large solids are present.

4. Bacteriological Processes.— In the filtration of water for dietetic purposes, it has been found that filters of fine sand, although they effect very little chemical change in the water, can remove from it nearly, if not quite, all of its bacterial contents. It has been found that if the sand used is first sterilised, it loses its power of removing bacteria (Piefke's experiments, P. Frankland, "Micro-organisms in Water", page 159.); that in fact the sand does not become efficient until it has acquired a coating of slime caused by the adhesion to it, and the multiplication and growth round the individual par-

ticles, of colonies of bacteria. These multiplying centres of bacteria serve as points of attraction and adhesion for the bacteria present in the water which is being filtered. The bacterial colonies are at first most numerous near the surface and gradually spread down through the sand. It has also been found that the efficiency of these water filters is inversely proportionate to the rate of filtration. Any increase of flow tends to increase the number of bacteria in the filtrate by washing them through. Much the same thing has been found in the filtration of sewage; in this case the rate of flow, and the coarseness of the materials used with the object of facilitating that flow, prevent all the bacteria being removed, but a large proportion of them do remain behind.

In the Massachusetts experiments with the filters described on page 104, the following percentages of the bacteria in the sewage were removed by the various filters:-
No 1. 60 to 74 per cent; No 2. 86 per cent;
No 3. 100 per cent; No 4. 95 per cent
No 5. 100 per cent; No 6. 95 per cent
No 7. 95 per cent.

It will be apparent from the above that the percentage of removal is directly proportion-

ate to the fineness of the material, and that those materials which removed a large percentage of bacteria are, as we saw before, too fine for practical use in sewage treatment.

By the treatment of sewage on sewage farms the bacterial contents are largely removed. Miquel states that Paris sewage contains on an average 13,800,000 microbes per c.c. before passing onto land at Gennevilliers, and that the effluent from the farm contains an average of 4,475 per c.c.. It must be remembered that ~~the effluent from~~ sewage is extremely variable in its bacterial contents, so that it might be easy to fall into error in this matter (Frankland op. cit. page 164.)

The Liquefying Processes seem more likely to add to, than to diminish the numbers of bacteria.

What then are the chances of destroying by these processes, or removing from the sewage by means of them, any pathogenic organisms which may be present?

In the processes which produce sterility of the effluent, they will be certainly destroyed, for there is no reason to suppose that they would behave differently from the ordinary bacteria present in sewage. Such processes are:— the Amines process, the Hermite process (under certain conditions), and filtra-

tion

tion through garden soil, heat, and very fine sand. In the other processes their chances of removal will be at least equal to those of the ordinary bacteria, and will therefore be proportionate to the number of the latter removed.

In the bacteriological processes another factor is introduced, or rather is likely to come more strongly into action than in the other processes. This consists of the conditions under which the bacteria are brought during these processes, and the antagonism which is known to exist between various forms. The sewage is placed under conditions which are known to favour the growth of certain species of harmless bacteria: these conditions certainly do not form the natural habitat of the patho-genic organisms, so that, even if they are not absolutely inimical to them, the latter stand a very good chance of being crowded out of existence by the luxuriant growth of the harmless species. Particularly is this the case where a biarefying process is first employed, followed by an oxidising one. Here the pathogenic organisms must run the gauntlet of two sets of circumstances, neither of which is presumably favourable to them.

Frankland made some interesting experiments on the behaviour of Typhoid bacilli in various waters with the following results. They lived for the undernoted number of days

	Sterilised	Unsterilised
Thames Water	32 days & more	9 days
Loch Katrine	51 days & more	19 days
Deep Well Water	20 to 32 days	33 days

Dr. Frankland found that in the unsterilised water, the common water bacteria multiplied most rapidly in the Deep Well water, while in the Loch Katrine water they rather declined in numbers. (Experiments quoted by H. Robinson, Op. cit, page 40.)

How the shorter life of the typhoid bacilli in the unsterilised Thames and Loch Katrine waters may be due to one of three causes.

1. The common water bacteria may actually attack and destroy or devour them.
2. They may use up food which is necessary for the nourishment of the typhoid bacilli.
3. They may produce some substance which has a toxic effect upon them.

The first cause can hardly be the true one, since, in spite of the common water bacteria multiplying more rapidly in the deep well water than in the other two, the typhoid bacilli lived in it for a longer time.

The second, though possible, would seem unlikely from the fact of the bacilli living longer in the unsterilised deep well water, than they did in the sterilised.

The third possible cause is probably the real one. ("Micro-organisms in Water" p. 228) Miquel showed that the toxic products produced by bacteria can be destroyed by boiling. Bacteria multiply much more rapidly in boiled water than in unboiled.

It seems unlikely then that pathogenic organisms will succeed in running the gauntlet of a complete bacteriological process for the disposal of sewage. If they do, they evidently cannot survive very long.

Wherever river water which may have been contaminated by sewage is used for domestic purposes, it must always be adequately treated by storage for a sufficient length of time, and by filtration through sand before distribution.

Summary of the various processes

From what has been stated regarding the various processes, we may conclude that the choice of a method must to a large extent depend upon local circumstances; it cannot be dogmatically laid down that any one process is the best for every locality. These local circumstances not only determine the mode of purification desirable, but may even affect the degree of purification which it is necessary to bring about. It may be well to recapitulate a few of these, before proceeding to individual methods.

(1.) The kind of sewage to be treated. It seems only natural, so far as our present knowledge goes, if it be not absolutely necessary, that manufacturers' refuse should be treated chemically. Hence in cases where chemical precipitation is not employed in the treatment of the whole volume of sewage, (and for that matter in every case), manufacturers should be compelled to treat their refuse before discharging it into the sewers. What the particular process, to which it is subjected, should be, depends of course on the individual composition of such sewage.

(2.) The size of the stream, into which the effluent is to be discharged, compared to the volume of the effluent. The bigger the stream the less absolute necessity there is for a constantly maintained high standard of purification. From the public health point of view it is of course always desirable that the standard of purification should be as high as possible; but any falling away from that standard is not betrayed so readily when the volume of effluent is small compared to that of the stream into which it is discharged. The deficiency is made up, and the process completed in the stream; the final stages of nitrification may be trusted to take place there. On the other hand, when the volume of effluent is large compared to that of the stream, the process adopted must be a very perfect one to avoid the creation of a nuisance. It must be remembered that the quantity of sewage previously received into the stream may make an apparently large stream really small, so far as its capacity for receiving an impure effluent is concerned. Rate of flow, aeration (produced by falls and otherwise), and proximity to the sea, are other

factors in the prospective recipient of the effluent which may influence the choice of a method for the treatment of sewage.
(3.) The nature, contour, price, and quantity of land, which may be available, have all to be taken into consideration.
(4.) The price of, and facility for obtaining certain materials such as lime and other chemicals, and filtering materials.
(5.) The probable market for crops such as grass and mangolds, and for manure.
There are always the two sides to the sewage disposal question — one, how to get rid most effectually of the sewage so that it will give rise to no nuisance, and cause no danger to life, including that of fish; the other, how to get rid of sewage as cheaply as possible. The idea of making sewage a source of profit to the community can only be carried out in rather exceptional circumstances.
The advantages and disadvantages of the individual methods, or groups of methods will now be summarised.

The Chemical Precipitation Methods

One fact regarding chemical processes seems now clearly established, namely, that

none of them can be said to form complete solutions of the problem of sewage disposal. Many of them act very efficiently as clarifiers of the sewage for the time being, but since they are only capable of removing a very small part of the putrescible organic matter in solution, the purification effected cannot be looked upon as anything like complete. Further treatment of the sewage is always necessary, if the liability to putrefaction of the effluent is to be obviated; this treatment must be in the direction of oxidation. It may be carried out with perfect inoffensiveness by discharging it into a river, provided always that the volume of sewage is small compared to that of the river (5% or less), and that the latter has not previously been polluted to any extent. If such a river be not available, it may be ~~accomp~~ accomplished by applying the effluent to land, or by artificial filtration.

Failing any such after-treatment, chemical precipitation can only be palliative, the nuisance caused by the crude sewage is only mitigated, not removed. This mitigation may be rendered greater, in some cases, by the addition to the effluent of various

substances which more or less easily part with oxygen, e.g. permanganates and nitre. It must also be remembered that by chemical precipitation the solids and any of the organic matter in solution which may have been removed from the sewage are not got rid of; they have been separated from the liquid, but they still remain to be dealt with. In many instances these processes having been worked successfully up to this point, have broken down through the difficulty in getting rid of the sludge. It seems most easily disposed of when the works are situated near the sea: the sludge can then be loaded in steamers and taken to some distance from land. "the success or otherwise of a precipitation process depends largely upon details in the arrangements, construction and management of the various parts of the works. The best process may fail by neglect of these details" (Report of Committee appointed by the Corporation of Glasgow 1888) Supposing all these difficulties to have been overcome, the subsequent oxidation of the effluent to have been provided for, as well as the disposal of the sludge, and attention to details, the precipita-

tion processes have still drawbacks from the point of view of getting rid of the sewage as cheaply as possible. The expense connected with them is considerable, chiefly under the following heads:-
(1.) The provision of tank accommodation amounting to nearly 50 per cent of the daily volume of sewage.
(2) Chemicals. — The cost of these varies a good deal but cannot be reckoned as much less than 20/ per million gallons.
(3.) The disposal of the sludge
(4) Attendance — wages and upkeep.
(5.) Any pumping required adds greatly to the expense of any process.
The principal, in fact almost the only advantage, that chemical treatment has over other methods of disposal, is the comparatively small area of ground required for carrying it out.
We may then conclude that the cases where chemical treatment is to be recommended as the best available process must be very few, except where it is employed with a view to getting rid of solids as a mere preliminary to some other process, and where accordingly the chemicals are used only in very small

quantities, and the amount of sludge is kept down to a minimum.

Electrical Methods

The Webster Process :— If all that is claimed for this process were true, it would be, so far as efficiency is concerned, an ideal one. It would combine the advantages of chemical treatment with those of land treatment, except in the matter of the utilisation of the sewage : it would combine the precipitation of the solids with the complete oxidation and destruction of the organic matter in solution, and the sterilisation of the whole, while it can be carried out on a limited area. There is some reason, it seems, to doubt the extent to which these claims are justified. It has been feared that the process is simply a roundabout way of treating sewage with ferric oxide (Dr. Thresh, British Medical Journal, Augt. 15th, 1891.). Besides those doubts as to its efficiency the process has very great drawbacks on the score of expense, both in the provision of the necessary plant, and of the electric power. Were the doubts proved to be to any extent groundless, the process might be suitable in a case where plenty of water-power was available and

where space was limited. Otherwise some of the bacteriological processes seem preferable.
Hermite Process :- Enough has been said already to show that the applicability of this method must be limited in the extreme.

Bacteriological Methods

From what has gone before, it may be concluded that in all probability sewage cannot be completely purified unless it be submitted at some stage to a bacteriological process, either planned and controlled, or under Nature's guidance. These methods have the great advantage of being in their essence Nature's methods of dealing with effete organic matter of every kind, and are for that reason alone most likely to prove the solution of the problem.
Sewage-Farming — is theoretically the most attractive of all the methods of sewage disposal. By subjecting sewage to this treatment any manurial value it may have is made the most of, while its purification can be carried out to the greatest Perfection. That it has proved thoroughly efficient in many cases there can be no doubt. What, then, are the objections to it,

and why is it not universally adopted as the solution of the sewage problem? The following are the objections which have been raised against sewage-farming:—
(1.) That pathogenic germs flourish in soil, and are apt to be transmitted to man and animals through the crops grown upon these farms. On this subject Riley (Yearbook of U.S. Department of Agriculture for 1895, p. 84) says. "For the reasons given above," (that pathogenic organisms can live in the soil), "the agronomist who also has at heart the health and welfare of man and beast can hardly look with favour upon any of the plans which have been proposed for the use of sewage from large cities for irrigation purposes. There is scarcely a time in any large city when some infectious disease, due to the activity of germs, does not exist, and the sewage is liable at all times to be contaminated therewith. In view of the fact that the vitality of the germs mentioned above may be continued for a long time in the soil, it is fair to conclude that it is of the utmost importance to avoid the contamination of the soil, where it is to be used for agricultural purposes, with any

of the dejecta which may come from those infected with any zymotic disease whatever."
On the other hand Dr. Alfred Carpenter contends (British Medical Journal August 25th 1888, and Augt. 15th 1891) that the pathogenic microbes are rapidly destroyed by the physical conditions under which they arrive at the farm, while their spores, which may survive exposure to these conditions, are absorbed and digested by certain classes of plants which he calls "carnivorous", including rye-grass. "The microbic life on sewage farms is antagonistic to the life of disease germs, the latter therefore soon cease to exist." This latter theory we have discussed.
There seems to be no authentic case of a sewage farm, which is well-conducted, causing injury to the health either of man or animals. Of course if not well laid out, if sewage be allowed to stagnate on the land, or if it be allowed to flow into some water-supply, the farm may very easily cause a nuisance and very serious injury to health. It is not fair to charge a system with defects of individual cases, which ought to be easily avoided or removed.
Dr. Meredith Young (British Medical Journal, April 25th, 1896) has investigated

the subject of the health of cattle fed on sewage produce. He finds that some cattle (perhaps not healthy) will drink polluted water, if they can obtain access to it. He thinks that, whatever be the effect of the consumption of sewage produce, there need be no hesitation in saying that the flesh and milk of animals, which have drunk sewage itself, should not be consumed by human beings till sufficient time has elapsed for the effects to pass away. He states that some farmers consider that milk has a bad taste when taken from cows fed on sewaged produce, that it has a heavy odour, and that its keeping qualities are impaired.

On the whole, then, the objection to a well-managed sewage farm, that it may injure the health of man and animals, is mainly theoretical: it is difficult to disprove, but there is really no concrete evidence on which it can be founded.

(2.) Financial Objections. — Sewage farms fail financially in some cases. Various reasons contribute to this result, among which are the following. (a) The sewage must be disposed of at all seasons of the year whether it is to the advantage

of the crops or not, and is often most abundant when the crops would be injured by it. (b.) The market for the crops is limited within a reasonable ~~dis~~ radius of the locality, and is apt soon to be glutted by the large production on such a farm. To remedy this a large expenditure of capital may be necessary in order that the produce may be consumed on the farm, and so its sale at a loss be avoided. (c.) The kind of crops suitable for cultivation on such a farm, especially if the intermittent downward filtration method be followed, is strictly limited. (d.) The great cost of suitable land within reasonable distance of large centres of population, and the large areas required for broad irrigation. This last objection does not apply so much to land for intermittent downward filtration, but for it again fewer soils are suitable.

The chief objections, then, to disposal of sewage on a farm in any individual case are likely to be financial. In some cases they may be so great as to put this method out of the question. For if the sewage can be disposed of as efficiently and more cheaply by some other process, we can hardly ask people to adopt sewage

farming simply to give effect to the abstract economic principle that the manurial value contained in the sewage should not be wasted.

The case where sewage-farming seems most likely to prove successful financially is where land of a porous nature, which in its natural state is barren, or not particularly fertile, and therefore worth little, can be obtained of sufficient extent. The sewage may then be applied either by broad irrigation, or intermittent filtration, or partly by one, partly by the other, according to the extent of land available.

These conditions are more likely to obtain in warmer countries than in this: there, also, the evaporation is greater, allowing much larger quantities of sewage to be applied, and it can be profitably utilised all the year round. Mr. J. M. Cook (British Medical Journal, Feb.y 9th. 1895) concludes that the system was "suitable to parts of India where the ground was permeable and the rainfall not excessive. It could be carried on profitably even where the flatness of the land necessitated the use of pumps, and should yield a much higher profit where the natural slope of the land

permitted them to be dispensed with."

Artificial Filtration. – The advantages of the employment of artificial filtration in disposing of sewage may be summed up as follows:–

1. The system is practically universally applicable; it requires no great area of land, since we have seen that a filter, one acre in area, is capable of ~~for~~ dealing with one million gallons of sewage per day from which the grosser suspended matters have been removed. The character of the land and the nature of the soil are of no importance.

2. Any degree of purification desired can be attained by varying the amount of sewage applied to the filter, the time for which the sewage remains in contact with the filter, and the duration of the intervals of rest.

3. The expenses of upkeep and working are small, practically no renewal of materials being required, while the filling and emptying may be automatically regulated.

4. The organic matter, produced by vital processes, is broken up and entirely destroyed by similar means. The agency employed is one which is essential to the

complete purification of sewage, whatever other process it undergoes. (This advantage may also be claimed for land-treatment.)

5. Although the process does not proceed so actively during cold weather, these filters are capable of turning out an effluent of a satisfactory character all the year round.

6. The cost of construction will, in a great many cases, be much less than that of the land necessary for use even on the intermittent filtration principle. They may be made active throughout their whole depth. The materials of which they may be constructed are not strictly limited. Many suitable materials are cheap, and easily obtained.

7. If constructed of adequate size, and properly worked, they cause no nuisance. The sewage is not seen (except on entering and leaving), because the filter must not be filled above the level of the material composing it.

The disadvantages are that the solids must first be removed in great part, and that the manurial value of the sewage is lost. The first objection applies equally to land, and can be easily overcome; the second may negative the use of artificial

filters if the value can, by other means, be profitably utilised.

Liquefying Processes.

These we have seen to consist in submitting the sewage to the process of putrefaction under a certain amount of control. That either of those we have described does its work well, there seems ~~to be~~ no doubt. Neither forms a complete process of purification in itself, but both ~~may~~ must be very useful preliminaries to the application of sewage to land or to artificial filters. For the effluent ~~from these processes~~ seems in no way to resist the action of nitrifying organisms, as is shown by Dr. Rideal's analyses.

The advantages of getting rid of solids through solution of them by one or other of those processes may be stated as follows:-

1. The solids are more effectively removed than by simple straining.
2. The processes are cheaper than chemical treatment.
3. No sludge remains to be dealt with.
4. The effluent contains the organic matter already started in the process which it must undergo before it can be of any use to crops, and to which it is subjected in an artificial filter.

5. The effluent contains all the organic matter originally present in the sewage, (except a little which may have escaped in a gaseous form), and therefore has a higher fertilising value than if the solids had been removed from it by any other process.

Both systems, however, seem to require the provision of a considerable tank capacity.

Conclusions.

What are the conclusions to be drawn from our consideration of the problem of Sewage-Disposal? Are there any general principles which may be formulated for our guidance in the selection of the best means of disposing of the sewage of any given locality?

We may state our conclusions in the form of the following general principles:—

1. That manufacturers' refuse ought to be treated and purified by the manufacturers themselves before its admission to stream or sewer. We have then practically only domestic sewage to deal with.

2. That removal of the solids in suspension ought to be the first step in the treatment of even sewage, even before discharge into the sea, and that this can best be attained by submitting them to putrefaction under control, by means of the Scott-Moncrieff, or "Septic Tank" system, thereby accomplishing their complete dissolution.

3. That thereafter discharge of the sewage into the sea may be permitted or into a

river, large in proportion to the volume of the sewage, previously unpolluted, and not used for domestic purposes lower down.

3. That, if such ~~a~~ means of discharge be not available, sewage, after removal of the solids, should invariably be utilised on land, where suitable land can be obtained at such a price, at such a level, and under such conditions, that there is a fair prospect of success attending the scheme financially and otherwise. The particular system of land treatment to be adopted must depend upon circumstances.

4. That, failing the possibility of acquiring such land under these conditions, the sewage should be submitted to "artificial filtration". The only disadvantage of this method compared with land treatment is that the manurial value of the sewage is lost.