Cantor lectures on bacterial purification of sewage / by Samuel Rideal.

SOCIETY FOR THE ENCOURAGEMENT OF
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Cantor Lectures

ON

BACTERIAL PURIFICATION OF SEWAGE.

BY

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SYLLABUS.

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BACTERIAL PURIFICATION OF SEWAGE.

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DR. SAMUEL RIDEAL, F.I.C.
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LECTURE I.—Delivered January 16, 1899.

The primitive mode of disposal of effete matters consisted almost entirely in the very effective method which is still in use in dealing with the dead, namely, a committal to earth. Deuteronomy xxiii., 12, 13, enjoins that all excreta shall be covered with earth, following the natural instincts of many animals. It will be noticed that this instinctive effort to cover the dejecta is most prominent in the carnivora, in which the matters are most nitrogenous, and therefore more highly offensive, whereas in the herbivora, no such natural propensity is observed. In the case of pastoral populations depending on springs and wells, water was too scarce and valuable to be purposely polluted. Those residing on the banks of rivers also refrained, to a great extent, from casting their refuse into the streams used for their bathing and drinking, and, having access generally to an ample amount of open and porous soil, employed what we may call the earth system. As soon as a portion of the population, for protection or convenience, became aggregated into settlements, it was early found necessary to set aside certain special places for the reception of refuse, hence the midden heaps that have been widely discovered in the neighbourhood of aboriginal villages. After a time for human excreta ditches or trenches were dug, from which the products of decomposition either sank into the surrounding soil, or found an outlet to some watercourse. In many cases trenches were at length filled in with earth, over which a rank vegetation grew, and the soil became gradually purified, a plan which is still followed in the case of temporary camps and in Eastern villages. At a later stage, when the progress of civilisation necessitated the use, for washing and cooking, of a larger quantity of water, isolated inhabitants found it difficult to dispose of the liquids, therefore great pits were dug to receive them, and to keep the rain out were roofed over with beams and earth. At a still later period these excavations were lined with brick, arched over, and connected with the houses by brick or flagstone drains. No cement, as a rule, was used in the construction, as it was found that if the sewage sank into the earth less frequent emptying was required. Moreover, if the receptacle or "cesspool" were made air- and water-tight by cement, it was necessary to provide a vent for the large quantity of gas that was generated in the decompositions. The author can record a case where a cemented cesspool in the north of England regurgitated a large quantity of sewage into the cellars of the house, allhough the pit had been recently erected, and was by no means full. In other cases unventilated cesspools have filled the basements of dwellings with sewer gas.

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

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

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

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

EFFECTS OF DILUTION.

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

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

Pettenkofer, from investigations on the river Isar, at Munich, has concluded that if the sewage never amounts to more than 1-15th, or 6·7 per cent. of the river water, and the velocity of the latter is at least equal to that of the former, the raw sewage may be poured into the river without causing pollution.

In America, from the results of actual observations on rivers, under the direction of the Massachusetts Board of Health, Rudolph Hering fixes a limit to the amount of free ammonia permissible in a stream, and finds that if the flow of a stream is less than 2½ cubic feet per second per 1,000 persons (or one gallon per minute per person), "an offence is almost sure to arise," but when the flow is greater than 7 cubic feet per second per 1,000 persons, then safety is assured. "In other words, when the free ammonia is greater than 0·12 parts per 100,000, the conditions are probably objectionable." These limits correspond to about 50 volumes of river water to average sewage in this country. Mr. Stearns, the engineer to the Massachusetts Board, concludes that if the average amounts to more than 1-40th, or 2·5 per cent. of the river water, it cannot he discharged into the river in its raw state; if it amounts to less than 1-40th, and more than 1-130th, it is doubtful; if less than 1-130th, it may be admitted without any doubt in its raw state into the river. These conclusions are, of course, empirical, and have not been generally accepted; they would be greatly affected by the amount of solid matter present in the discharge. It must be remembered that the sewage in America is much more dilute than in this country, that the rivers have greater volume, and that the limit is much higher than we have found necessary in England.

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

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

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

Where the sewage is fresh, and no nitrates have been formed—

$$XO = C\,M\,S.$$

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

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

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

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

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

It will be noticed that the characteristics of sewage are the converse of a pure running stream; and this is true, not only from the chemical point of view, but also when one studies the normal flora and life in the two. In a well oxygenated river the water bacteria are mainly aerobic, and carrying out their life-work of oxidation of the nitrogenous and carbon compounds presented to them. In a sewage, on the other hand, dissolved oxygen is usually absent, or, if present, soon disappears on standing, so that the organisms capable of living in this environment must perform their life-work without free oxygen. The water bacteria have been studied for many years, and those commonly occurring in river water are well known. Sewage organisms have only attracted attention during the last few years, and bacteriologists are now engaged in identifying the flora of different sewages, with especial reference to the changes which they effect in the chemical constitution of their environment. It would seem, therefore, from the outset, that if these sewage organisms have any useful part to play, similar to that which they naturally do, in any modern system of sewage disposal admixture with river water, in which an entirely different set of organisms live, or exposure to the air, must be avoided. We have seen that in the two earlier methods of disposal, viz., committal to earth and the cesspool, absence of light and air were obvious conditions obtaining in both; and now, with our modern knowledge, we can say that these two conditions were favourable to the life-work of the organisms concerned in the destruction of the organic matter. With the introductiou of the water-carriage system a departure from these conditions was made, and the difficulties which have since arisen can, in most cases, be attributed to a violation of one or other or both of them. When sewage is discharged untreated into a river, as we have just seen, sewage conditions or river conditions will exist after admixture, according to the ratio of the admixture. As sewage conditions involve absence of light and air, they will continue at the bottom of the river unnoticed if sufficient river water is present to mask these initial changes which must take place. If the river be a small one the sewage conditions may predominate, and constitute a nuisance which is all the more marked because the changes involved take place unobserved (out of the air) and unseen (in the dark).

It will be out of the scope of the present lectures to enumerate the characteristics of any of the water organisms concerned in the chemical changes taking place in a running stream. It is evident, however, that they normally can deal with the food supply presented to them, and the whole of the life of the stream is determined by their activity. At the present time it is becoming daily more possible to detect whether a river water has a flora which in any way departs from the normal, so that evidence of sewage pollution may now be ascertained by a careful examination of the types of water organisms present. Thus, for example, recent work on the organisms present in London sewage by Dr. Houston, for Dr. Clowes, the chemist of the London County Council, has established the following facts:—

Bacillus fluorescens liquefaciens and *B. fluorescens non-liquefaciens*, were generally, but not always, discovered. The bacteria causing fluorescence do not seem to be so prevalent in the London sewage as in that from other sources. Both the above are frequent in natural waters.

Proteus.—The species most abundant was not the typical Proteus vulgaris, but liquefying and gas-forming protean forms were very numerous.

B. coli communis is constantly present in very great numbers. This organism is absent, at all events in any numbers, from pure waters. Varieties of the Coli group are also abundant.

Of spore-bearing bacteria, the spores of *B. subtilis*, *megaterium*, *mycoides*, and *mesentericus* were frequently found. These are chiefly notable for their great vitality and resistant powers, but are also met with in natural waters.

B. enteritidis sporogenes (Klein), was constantly present: it is believed to be causally related to diarrhœa. Cultivations of it are extremely virulent.

Unfortunately, many of the organisms enumerated also occur in river waters which presumably are pure, so that their value for diagnosing the presence of sewage in water is only of slight value. Dr. Houston, however, points out that the *B. enteritidis* of Klein is so characteristic of sewage that its presence in a river water may be regarded as a sure sign of the addition of sewage. This organism, like other typical sewage organisms, thrives in the absence of air, and is recognised by its coagulating effect upon the organic solids of milk, a property which the ordinary water bacteria lack.

Seaside towns usually discharge their sewage on the foreshore near low-water mark, but a great portion is returned by the tides, and the serious nuisance often occasioned has led to agitation against this practice. Sea water is not a satisfactory medium for the purification of sewage, partly because it contains a comparatively small number of water bacteria, but mainly because the tidal disturbances prevent sedimentation of the suspended organic matter, which allows, as we have seen, the organisms which live in the absence of air and light to do their necessary work.

A partial return to earth-disposal was seen in the adoption of irrigation, but the experience gained on sewage farms, and the study of nitrification by bacteriologists, have shown that, in the case of land treatment, different soils have very varying efficiencies. Thus the earlier experiments seemed to show that the "cleansing" power of a soil was determined entirely by its physical condition, porosity, freedom from clogging, water-retaining power, &c.; whereas at the present time we know that the composition of the soil and its bacterial condition modify the results. In some soils nitrification either does not take place at all, or goes on with extreme difficulty. Crude sewage discharged direct on land rapidly coats it with a felted layer of black decomposing matter, which hinders the access of oxygen, chokes the plants, and soon creates a nuisance, unless the soil is exceptionally sandy or porous as in the neighbourhood of Berlin.

Great diversity of opinion existed as to the best vegetation for a sewage farm. Root crops and Italian rye grass found favour on some farms, while osier beds met with success on others, and owed a portion of their usefulness to their acting as a mechanical strainer. At Sutton, in recent years, peppermint has been found profitable, whilst sunflowers have been advocated as a suitable quick-growing crop. But the results were above all dependent on the soil. Thus Dr. Frankland, in 1870, speaking of a sewage farm at Barking, remarks on the slowness of nitrification, while with regard to a loam from Dursley, in Gloucestershire, he found that it surpassed all others experimented on in its power of purifying sewage, as it had a cleansing power of nearly 100,000 gallons per acre per day. We now know that the presence of carbonate of lime, or of gypsum, is favourable to the growth of nitrifying organisms, and the Dursley soil contained 8·1 per cent. of $CaCO_3$, while that at Barking had less than 2 per cent.

I had lately to determine the merits of alternative sites for a sewage farm in the Midlands. The average amounts of water in the three soils were 6·75, 1·90, and 3·05 per cent., while their comparative nitrifying power, as shown by their action on dilute urine, was 17, 50, and 36, which is almost exactly in inverse ratio to the amount of moisture, showing the powerful adverse retarding influence of a water-logged soil.

The unsatisfactory results on sewage farms led to the opinion that the sewage should be first prepared, and a "combined system" of treatment was prescribed almost universally by the Local Government Board. The details of different processes of screening, filtering, sedimentation, and the use of precipitants are beyond the scope of these lectures. It is sufficient to say that the removal of suspended matters, and a greater or less reduction of those dissolved, was attained, it was then considered, mainly by physical or chemical means.

One cannot, however, omit to draw attention to the almost universal adoption in this country of different methods of chemical precipitation after the River Pollution Commissioners issued their report. This was in great measure due to their finding that chemical precipitation effected the removal of the greater part of the suspended organic matter, and of some of the dissolved organic matter. This result was seized upon as a practical method of dealing with the sewage problem, as the effluent after such chemical precipitation was obviously less foul than the raw sewage. It was forgotten almost entirely, however, that the Commissioners, in the same report, distinctly state that just as good results could be obtained by upward filtration; in other words, if the sewage were allowed its conditions of absence of air and light, it could be brought into solution and towards purity. It was also not recognised at that time, that chemical precipitation, while removing the suspended polluting matter, would also remove the concomitant bacteria from their sphere of usual action, and thus prevent any desirable changes naturally brought about by them. Likewise also, it was not realised that heavy doses of chemicals were likely to be inimical to these beneficent bacteria to such an extent that they might be killed or their work arrested.

The conclusion of the Massachusetts Board, in their report of 1890 (p. 788), showed that "it is quite impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand." It would thus seem that for nearly 20 years the almost universal practice of chemical precipitation had been wrong in principle, and that the example set by Merthyr Tydvil in 1871 should have been followed. This town then contained 50,000 inhabitants, and the sewage, after treatment with lime, was subjected to intermittent filtration through 20 acres of porous soil drained from 5 to 7 feet deep, under the superintendence of Mr. Bailey Denton. From the analyses made by Sir E. Frankland in 1871-2, I have prepared the following averages, adding also his "proposed standards of purity."

	Dissolved Solids.	Organic Carbon.	Organic N.	NH_3	N as Nitrates and Nitrites.	Total combined N.	Cl.	Suspended Solids.	
								Mineral.	Organic.
"Proposed Standards"	Unlimited	2·0	0·3	Unlimited	Unlimited	Unlimited	Unlimited	3·0	1·0
Sewage after liming	52·0	2·44	0·9	2·7	·017	3·18	5·98	11·8	21·6
Filtrate	33·2	0·14	0·03	·063	·273	·348	2·74	trace	trace
Subsoil water	19·4	·106	·011	·004	·061	·075	0·9	—	—

The figures show that the sewage has undergone dilution with more than its volume of subsoil water, and probably with some rain, as the mean dissolved solids of the sewage and subsoil water are about the same as those in the effluent, while the chlorine in the effluent is less than half that in the sewage. But even with this allowance, the result justifies Frankland's pronouncement that "the effluent water on all occasions was purified to an extent much beyond that required by the standards of pollution suggested by us as those below which refuse liquids should not be permitted to enter rivers." The analyses are of further interest at the present time, as we can see from them that:—

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

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

The large reduction in organic nitrogen was doubtlessly occasioned in part, at first, by its absorption by the soil, but as the analyses extended over nearly a year and half, and the later ones showed the same changes, this mechanical absorptive action must be excluded as an unimportant item.

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

Even under favourable conditions the results of irrigation are dependent upon the degree of skill with which the work is directed. When sewage is poured over clay-land which cracks in dry weather to the depth of the underground drains, it escapes in such weather almost immediately from the field in an imperfectly purified condition. When allowed to flow over an uneven surface, or without a regulated flow, it is certain to form stagnant pools in which the plants are injured, or only rank weeds are produced. All the uncertain conditions with which a farmer has to deal are complicated by the stream of sewage. Although the opposition almost invariably encountered in the establishment of sewage farms, on account of the nuisance often occasioned and the expected injury to health, does not seem to be well-founded where the management is efficient, the hope of return of capital has had in nearly all cases to be abandoned, on account of the initial cost of the necessary land and the poor return from the crops grown. For these reasons the insistance of the Local Government Board on a final treatment by land has met with very severe comment, especially since it has been shown to be practicable by bacterial agencies to accomplish the object with less attention, space and cost, and with more regularity. At the same time all these rudimentary methods which have been described have depended for the final stage of purification on the assistance of a river, or of porous land.

Lecture II.—Delivered January 23, 1899.

A partial recognition that natural purification of organic matter was due to living organisms was arrived at early in the present century, when Cagniard de la Tour discovered that yeast was a living plant, and Schwamm demonstrated that putrefaction was due to something in the air which heat could destroy, and that meat would not putrefy in calcined air. It was suspected therefore that organisms were the actual cause of decay and putrefactive change, but the powerful advocacy of Liebig and his school of the so-called "Catalytic" theory delayed the general acceptance of the "germ theory" for more than thirty years. It will be recollected that in the catalytic theory it was believed that some organic substances, in the act of undergoing decomposition, possessed the power of causing the alteration and decay of other organic substances in contact with them, and this mechanical, as distinct from a biological, explanation, held its own until Pasteur proved that fermentation and putrefaction did not take place in the absence of living organisms, which he divided into aerobic, or thriving in presence of oxygen, and anaerobic, or growing without it. Their life history and characters have since been elaborated by Koch and a number of other observers. On the other hand, the well-known purifying action of soil, beyond the mere mechanical straining, was, up to a late date, considered to be purely chemical, and due to oxidation. E. Frankland, in 1872, had pointed out that "a filter must not be considered as merely a mechanical contrivance, the process carried on being also chemical." This was true, but the necessity of the co-operation of life in the processes was at first almost ignored, more especially as in nitrification, one of the most important of the actions, no accompanying special organism had been discovered. We now know that this was due to the fact that the microbic group responsible for nitrous and nitric changes would not grow in the gelatine or other media ordinarily used for cultivations. The researches of Warington, P. Frankland, Schloesing, Winogradsky, and others, resulting in the isolation of nitrifying and denitrifying organisms, removed the difficulty, and, in 1872, the Berlin Sewerage Commission reported that sewage matter was converted into nitrates, not by a simply molecular process, but by organisms present in natural sewage and soil. Muntz, Müller, Marie Davy, and others also demonstrated in various ways how the purification of sewage was accomplished by bacterial action.

Sorby, in 1883, remarked on the very large proportion of the detritus of fæces which was lost in the river, owing to the action of "countless thousands of living creatures," and Dupré, in a report to the Local Government Board in 1884 on the results of his experiments on aeration, stated that "the consumption of oxygen from the dissolved air of a natural water is due to the presence of growing organisms, and that in the complete absence of such organisms little or no oxygen would be thus consumed." In May, 1886, Dupré proposed "to cultivate the low organisms on a larger scale, and to discharge them with the effluent into the river, as the power these lower organisms had was remarkable."

In the following January, Dibdin, speaking at the Institute of Civil Engineers, on the precipitation of sewage, observed that "One object claimed for the use of an excessive quantity of lime, and also for some other substances, is that they destroy the living organized bodies, such as bacteria, &c., which gave rise to the phenomena known as putrefaction. . . . As the very essence of sewage purification is the ultimate destruction, or resolution into other combinations, of the undesirable matters, it is evident that an antiseptic process is the very reverse of the object to be aimed at."

In this connection the same authority has remarked that "very alkaline effluents, such as those produced by the use of lime in excessive quantities, are very liable to putrefy instead of becoming purified by oxidising organisms."

In 1887, the Massachusetts State Board commenced their well-known series of experiments on the purification of sewage by filter beds, showing the effects of intermittent filtration with the aid of aerobic bacteria, and working out details of various porous materials, size of grains, thickness of strata, influence of time, temperature, and different methods of procedure. The results were on rather too limited a scale to be exactly comparable with practice, but the general deductions have been amply confirmed by the success of larger sewage works on biological principles both in Europe and America.

It soon became evident that if a filter bed were worked continuously, it rapidly choked, and putrefaction occurred in the interior owing to a deficiency of aeration, so that on the aerobic plan it was necessary to work intermittently, draining out the liquid, and allowing the entrance of air during regular intervals of rest.

Otherwise it was necessary to have "very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact," a condition, however, which did not prevent the sand filters from becoming overburdened and also greatly limited the amount of sewage treated. In the Massachusetts Report of 1890, the process is compared to a combustion, and was found to be most rapid in the summer months. The same Report gives useful information on the methods of analysis, besides observations of the number of bacteria and algæ, and valuable descriptions of the species found in the effluents. It must be remembered that sewage in America is usually weaker and of greater volume than it is in Europe, on account of the more abundant supply of water.[*]

The sewage of Lawrence City, in the Massachusetts investigation, had been run on the filters without any previous purification, or even settlement. On the other hand, our sewage of London had undergone a previous preparation, by being treated with 1 grain per gallon of ferrous sulphate and 4 grains of lime, the precipitate of sludge being then conveyed in boats to be discharged at the mouth of the Thames. It was hoped that the clarified liquid, after the precipitation, could be discharged into the river direct without creating nuisance. But it still contained about 10 parts per 1,000, or 7 grains per gallon of suspended solids, and was by no means free from odour. The Royal Commissioners of 1884 had decided that the liquid could not be discharged at the outfalls as a *permanent* measure, and required further purification by application to land.

In 1866 an experiment with London sewage

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[*] The daily consumption of water per head in New York is 92 U.S. gallons; in New Jersey town and cities, 92 gallons; in Philadelphia, 143; in Los Angeles, California, 200; in Alleghany, Pennsylvania, as much as 247 gallons. (10 U.S. gallons = 7 imperial.) (Mason.)

as applied to land had already been made at Barking. The Metropolis Sewage Company obtained a concession to treat the sewage of North London, amounting to about 2,000 tons in 9 or 10 hours, on five or six acres of grass land on a light gravelly soil. The experiment was not a success, either culturally or with regard to the cleansing of the effluent. But when we come to the 200,000,000 gallons daily of London sewage, it will be obvious that the requisite area of suitable land is entirely unattainable. This being recognised, and an extension of chemical treatment and precipitation having proved to be inadequate as well as costly, the Main Drainage Committee of the County Council in 1891 determined on a series of experiments at Barking outfall, on the lines of the Massachusetts researches. From the preliminary investigations with small filters, it was considered that coke-breeze was the most suitable material, although burnt ballast was found to nearly equal it in purifying efficiency. Sand and gravel effected a greater clarification, but the removal of dissolved organic matter, as measured by the reduction in the oxygen consumed, given in Mr. Dibdin's Report, was considerably less than with the coarser materials. Moreover, there seemed a tendency for the effluent to become putrid, owing to deficient aeration from the closeness of texture, while the filter required frequent scraping and renewals. The average rate of working, including periods of rest, was 411,000 gallons per acre, or 250 gallons per square yard, in 24 hours. For eight hours a day the effluent ran continuously, the filters being kept full; the filter was then emptied, and allowed to rest for 16 hours.

The figures given by Messrs. Dibdin and Thudichum, who conducted the experiments, are as follows:—

Clarification, as measured by the units of depth required to obscure standard mark:—Burnt ballast, 1; coke breeze, 1; pea ballast, 1¾; sand, 2¼.

Reduction of Organic Matter (oxygen consumed):—Burnt ballast, 43·3 per cent.; sand, 46·6; pea ballast, 52·3; coke breeze, 62·2.

The report adds significantly "the number of organisms in the tank effluent before filtration, and in the filtrates, was found to vary very considerably, *those in the filtrate being generally present in larger numbers*; but it soon became apparent . . . . . that the presence of a large number of organisms was evidence of the activity of the process of splitting up the organic compounds in the sewage matters passing through the filters. Here it is clear that the main purification was bacterial, and only the beginning of a further resolving change to be carried on in the river. It would undoubtedly have been an advantage if the biological process so initiated could have been allowed to develop a further stage in the filter, but the prescribed object of the experiments was the attainment of the highest rate of speed consistent with such purification as would remove the obvious objectionable characters such as odour, colour, and liability to putrefaction."

The further experiments with a one-acre coke breeze filter at Barking are well-known. As at Massachusetts, it was found that continuous running resulted in clogging and a foul effluent, and that to obtain the best results the commencement must be made with small quantities of liquid, the filter, which was composed of 3 feet of coke breeze and 3 inches of gravel,

TABLE I.—AVERAGE ANALYSES FROM ONE-ACRE FILTER (DIBDIN).

Parts per 100,000.

Date.	Average per acre per day.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Per cent. purification by oxygen absorbed.
	Gallons.	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
April 7th to June 9th, 1894 ..	500,000	5·85	1·23	·593	·138	·182	·340	79·3
Aug. 3rd to Nov. 9th, 1894 .	600,000	5·18	1·42	·565	·158	·032	·200	79·6
Nov. 1894 to March, 1895....	1,000,000	5·87	1·33	·545	·160	·565	1·00	77·5
April 8th to April 20th, 1895..	1,000,000	5·00	1·26	·514	·146	·224	1·10	75·4
May to Sept., 1895..........	1,000,000	6·62	0·91	—	—	—	—	80·7

being at first merely filled and emptied twice daily, with a view to obtaining an active bacterial bed. Daily determinations were made of the oxygen absorbed, albuminoid ammonia, and nitrates. At the end of a month, when the highest efficiency was reached, amounting to 83 per cent. purification, the quantity of effluent was increased by stages to one million gallons daily, while the time of rest was shortened. The filter was finally worked on the system which has been found the best at Barking, Exeter, and Sutton, namely, alternate filling, resting full, and emptying, with a periodical entire rest empty for complete aeration. At Barking, the filling occupied two hours, the standing full one hour, the emptying five hours, so that three cycles of eight hours were completed each day. From 10 p.m. on Saturday till 6 a.m. on Monday the filter rested empty, making a period of 32 hours each week. This weekly rest involves the storage of the crude effluent in reservoirs for the corresponding period—a practice which has many objections. At Exeter, where the flow through the septic tank is continuous, and no reservoirs are employed, the cycles are continued, by means of the automatic gear, throughout the entire week. Should a filter show signs of exhaustion, which occurs at long intervals, or rarely through accident, it is thrown out of use for one or two weeks till recuperated.

The one-acre filter is still in use. It is reported that after five years' working it is free from clogging, and its working capacity is not impaired. Its depth is now being doubled, to see whether any increase of efficiency will ensue from a deeper layer.

At the period when it was believed that the purification of sewage was almost entirely effected by chemical processes of oxidation, attention was divided between chemical methods of oxidation by materials like the manganates, permanganates, chlorine, and others, which proved in practice to be expensive and not final, and mechanical devices for freely exposing to air, or even forcing it continuously or intermittently into the liquid. The patents are very numerous, and include the use of perforated screens, weirs, cascades, and the use of air heated, charged with vapour, or under pressure. Electrolysed sea water, and other electrical processes have also been tried without much success. Many of these have been started with an idea that the final products might have a sale which would help to balance the cost of the process. But since this hope has not been realised, chiefly on account of the great dilution, even a strong sewage only containing about 100 parts of total solids in 100,000, or 0·1 per cent., a great part of which is worthless inorganic matter, and only about 20 to 30 parts per 100,000 of nitrogen in all forms, with an even less proportion of other substances of value, it soon became evident that the only expenditure which could be incurred was that which was rendered absolutely necessary for sanitary reasons. Therefore the introduction of the natural, and to a great extent, automatic process, was an immense advance. Yet while exclusive attention was given to the aerobic organisms, various schemes were proposed for the artificial aeration of the filters.

Under Lowcock's system, as described in a paper read before the Institute of Civil Engineers in 1893, air was forced under an average pressure of 4½ inches of water, either continuously or at intervals into the body of the filter, which was constructed at Malvern of gravel, and afterwards, at Wolverhampton, of coke breeze. The filtering area required is 3·8 acres per million gallons for crude, or one acre for chemically treated sewage, the percentage purification of the sewage being "considerably over 90 per cent." At the same time, the expense of pumping air must needs be very great.

About the same time Waring, in America, proposed a method of forced aeration which differs from Lowcock's mainly in the separate treatment of the sludge by means of "aerators." The system, which is somewhat complex, was first installed at Newport, N.Y., in 1894.

This city was sewered under the combined system, and the liquid became frequently admixed with sea water entering the sewers, the effect being an increase of the suspended solids by precipitation of soap and other matters. This precipitation has been often noticed in tidal reaches, and has resulted in the formation of banks and deposits on the bed. It would seem that the lime and magnesia present in ordinary waters do not secure the removal of all the higher fatty acids as the greasy scum seen frequently in sewers. From examination of the soluble part of sewage I have found that soda salts of oleic and other fatty acids are still present, especially in towns with a soft-water supply, owing probably to the influence of the ammonia formed. These soluble soaps are decomposed and precipitated by the high amounts of calcium and magnesium salts existing in sea-water, so that the sewage of Newport contained unusual amounts of soap curds.

The sewage first passed through a settling chamber for road detritus, and was thence pumped alternately through either side of a divided tank containing a shallow bed of coarse broken stone to arrest the coarser solids. "The impurities in the section thrown out of use disappeared rapidly in its interval of rest."

The liquid next passed slowly through four straining tanks filled with stones and gravel, whose function was said to be "mere mechanical sedimentation." As soon as these became clogged a plug was drawn, and the sludge emptied into a separate "aerating tank," filled with stones and gravel, where air was driven constantly through the mass, and as soon as active bacterial action had set in the sludge was rapidly dissolved.

Air was also forced through the straining tank till it was again in condition for use. Apart from the complexity of the system, we have here, in place of the regular intermissions for rest and aeration as used in England, a continuous working, assisted by forced aeration, with its accompanying expense, at longer intervals, the compensating point being claimed that a larger volume of sewage can be treated. The action here is obviously entirely aerobic, but as we shall see later, can be obtained better by a preliminary anaerobic treatment.

Following the success of the Barking experiments, an installation on the same principle was started at Sutton, Surrey, at the beginning of 1894. The filters were of different materials, but again showed coke breeze to be the best, with burnt ballast as a good second, the latter being very simply constructed by digging out the clay to form a pit about 3 feet deep, and filling it up with the same clay after burning, the cost of a filter of this kind, having an area of rather more than one-tenth of an acre, being given as less than £100, including all charges. It will be remembered that the cost of the Barking one-acre coke filter was stated as £2,000.

Up to this time the filters had been fed with an "effluent;" that is, a sewage prepared by straining, partial chemical precipitation with lime and ferrous sulphate, and sedimentation. In November, 1896, it was determined to abandon precipitation and to prepare the crude sewage, after the removal of the grosser particles by screens, by running it into a "bacteria tank" containing coarse burnt ballast, previously inoculated with a liquid containing the bacteria which had been found effectual. The fluid from the tank was further purified, as formerly, by coke breeze filters.

After three months' working Mr. Dibdin was able to give a satisfactory report. The oxygen consumed by the organic matter was reduced by the tank 66 per cent., and by the filter beds to 86·5 per cent. The solids in suspension were reduced by the tank 95 per cent., and by this and the filter 99·6 per cent., while the filtrate was practically clear, had no objectionable odour, and did not putrefy on keeping. The process has continued to the present time with satisfactory results, except when the filters were overtaxed, "some of them," as Mr. Dibdin reports, "having been purposely worked up to a rate of nearly three million gallons per acre per day, with the result that the bacterial action was evidently checked, as shown by a decrease in the production of nitrates and an increase in the quantity of organic constituents in the effluent. As the result of careful watching, however, no permanent harm was done, as the filters were immediately restored to their usual condition, when they proceeded to give good results."

This remark points to the conclusion that when there is reliance on presumably aerobic filters and organisms for combined liquefaction and nitration, indiscriminately, in the same receptacles, the result is apt to be variable, and to depend on "careful watching," an inference that is borne out by Mr. Dibdin's figures as given in his later report of analyses during 1896 and 1897.

The average results in his Table I have calculated, for the purpose of comparison, to a uniform chlorine content of 12·84 parts, which is the average given for the Sutton crude sewage.

It will be observed that the chief purification occurs in the bacterial tank, and that a large proportion of it consists in the removal of the suspended solids. The following are further particulars of the Sutton Works :—

The bacteria tanks are three in number, contain 3½ ft. of burnt clay ballast, and are 183 square yards in area. The times required are :— Filling ¾ hour, resting full 2 hours, emptying 1¼ hour, resting empty 2 hours. Two or sometimes three cycles are completed per day, according to the flow.

The population of Sutton is 13,000, and the daily dry weather flow of sewage, on the separate system, is 350,000 gallons. At present only part of the sewage is treated bacterially. The beds have been working for the last three years, the coarse bed dealing with the screened sewage at a rate of about 100 gallons per square yard per day, and the fine bed at a rate of about 150 gallons per square yard per day; 10 acres of beds are therefore required to treat 3,000,000 gallons of sewage per day after it has been properly screened.

During the two hours of resting full, a mixture of organisms, of which I believe a great proportion are anaerobic, as indicated by the large production of nitrites, are liquefying the sludge. It was estimated that in the three tanks 80 tons of dry matter had been thus reduced from November, 1896, to December, 1897. During the period of resting empty, the aerobic bacteria are supposed to be at work, although, according to Mr. Dibdin, no air enters except that drawn in while emptying out the liquid. The subsequent coke breeze filter is intended, under the same conditions, to be entirely aerobic and nitrifying. Here also the presence of nitrites may be remarked.

It will be noticed, further, that the Sutton sewage has already been broken down to a very considerable extent, as shown by the 12·53 parts of free ammonia, and only 1·13 parts of albuminoid.

An automatic rotary screen is used to intercept the coarser matter before the sewage is applied to the tanks. The amount of this intercepted material is stated in Mr. Thudichum's recent paper (Soc. of Engineers, Dec. 5th, 1898) to be about 30 barrow loads per day per 1,000,000 gallons. Mr. Thudichum also remarks that "practical points requiring further investigation are the trapping of sand, the duration of life of the coarse beds, and the degree of fineness for the screens. In the septic (Cameron) tank everything organic may be permitted to enter."

Table II.—Sutton System (parts per 100,000).

	Cl.	Oxygen absorbed in 4 hours.	N as nitrites.	N as nitrates.	Free NH_3.	Albuminoid NH_3.	Suspended matter.	Residue on micro-filter millimetres per litre.
Crude sewage ...	12·8	6·49	·021	None	12·53	1·13	85·76	3000
Tank effluent......	12·8	3·06	·301	·751	3·85	0·60	5·1	213
Filtrate from coke breeze	12·8	1·19	·087	1·99	1·25	0·316	1·35	23

These figures show the following percentages of purification :—

	Oxygen absorbed.	Free NH_3.	Albuminoid NH_3.	Suspended matter.
By the "bacterial tank"........	53	69	47	94
By the coke filter	29	21	25	4·4
Total purification	82	90	72	98·4

At Oswestry the Sutton system was adopted in the beginning of 1898. The material for the beds was obtained by screening from an old refuse tip, from which, according to the engineer, everything excepting hard carbonaceous matter had disappeared. The coarser portions are used for the "primary" filters, 4½ feet deep, corresponding to the Sutton "bacteria beds," and the intermediate portions for the "secondary" filters, 4 feet deep, intended to be equivalent to the Sutton coke breeze. This screened refuse costs about 1s. 3d. per cubic yard in the filter beds, and is believed to be already charged with organisms. The crude sewage is not passed at once on to the beds, but is previously clarified by subsidence in settling tanks. The report states that about half the sludge settles in these tanks, and is removed weekly, mixed with the dust screened out of the town refuse and sold as manure. The population of Oswestry is 10,000, the dry weather sewage 300,000 gallons per day, and the water supply 20 gallons per head. Total costs of works (when completed) £1,800, annual working expenses about £80.

Other experiments carried on during the past twelve months with the Sutton method on the sewage of Leeds at first showed considerable difficulties owing to "sludging-up" of the beds, but by increasing the periods of rest so as to allow the retained organic matter to be dissolved, and by the introduction of finer screens which remove a greater portion of the suspended solids (sludge) to be otherwise dealt with, more satisfactory results are being obtained.

It is remarked, however, in the Leeds report, that if the resting period were too prolonged, "the large increase of capacity gained by rest was, to a great extent, lost within a short time" (p. 33). Thus, after a suspension of 38 days, the capacity was reduced in a fortnight from 56,500 to 45,800, or 10,700 gallons. I would venture to suggest as a reason that the long aeration had destroyed or enfeebled the anaerobes, and that the liquefaction was therefore suspended until an anaerobic state was restored.

Colonel Harding (the Lord Mayor) and Mr. Hewson, the City Engineer, who together drew up the report, conclude as follows:—

"The question is raised as to whether an experiment should not be made without delay to ascertain the effect of the septic tank treatment for the destruction of the solids in suspension; also to see how far an open (?) septic tank, or upward septic filtration through coarse material, covered with a layer of sand, would be effective in destroying the sludge, and so far relieving the filter beds."

With Leeds sewage, the experience gained shows that 400,000 gallons per day can be dealt with on ½ acre of coarse bed and ½ acre of fine bed, or 1 acre per day in all, after the grit has been removed in a settling tank, and the grosser solids (paper, fibre, &c.) screened off. This gives a minimum of 50 acres of beds for 20,000,000 gallons; but in order to have spare beds, it is recommended to have 70 or 80 acres, or say 4 acres per 1,000,000 gallons.

Leeds, under the old system, would have to deal with 300 tons of sludge per day, or say 100,000 tons per annum. By settling the grosser solids, the suspended matter could be reduced, according to the same report, from 37·2 grains per gallon to 25 grains per gallon, and the filter beds would not then sludge up. This leaves, however, about one-third of the total quantity, corresponding to the 100 tons of sludge per day of the present precipitation process still to be disposed of.

DUCAT FILTER.

Colonel Ducat, with a view of introducing automatically a larger supply of oxygen, has devised a filter with walls composed of perforated tiles, or of drain-pipes laid horizontally, so that air can have free access to the body of the material without pumping. The bed is coarse-grained above and fine below, and the action is intended to be exclusively aerobic, as atmospheric oxygen in excess is brought in contact with the contents at once without giving any period of anaerobic incubation, and therefore presents some points of resemblance to the Waring process already mentioned. I have pointed out elsewhere that in towns with old and long sewers, or where storage is practised, the liquids may have already received sufficient hydrolytic resolution to be quite prepared for a strong aeration such as this filter supplies. This is illustrated by an analysis furnished by Dr. Houston:—

	Oxygen absorbed.	Free ammonia.	Albu-minoid ammonia.	Oxidised nitrogen.
Sewage, Oct. 14th, 1898	14·72	8·7	1·6	—
Filter effluent, ditto....	0·78	0·3	0·094	·477

The high free ammonia and the low albuminoid shows that the sewage has already undergone the preparation I have mentioned. The nitrification of the effluent, indicated by the "oxidised nitrogen," has not proceeded as far as might have been expected, notwithstanding the very large loss of ammonia. The oxidation of the carbonaceous matter to carbonic acid is also most marked.

The system is under trial at Hendon, and also experimentally at Sutton.

GARFIELD COAL FILTER.

Dr. Bostock Hill, in a paper at the Leeds Sanitary Congress in 1897, gave a very favourable account of the use of fine coal for the filtration of effluents which had been previously chemically precipitated, at Wolverhampton, Lichfield, and other places. The sewage of Wolverhampton is heavily polluted with chemicals, that of Lichfield contains a large amount of brewery refuse. Dr. Hill observes that "the action of coal is different from that of other media in that analysis shows a far greater difference in the oxygen absorbed before and after filtration than in the organic matter as measured by albuminoid ammonia."

"As far as is known any kind of coal will do, but it should be as clean as possible, and the depth should not be less than 5 feet." At Lichfield the first layer, over the drain pipes, is ½-in. cube coal, then a little ¼-in., afterwards 2½ feet of 1-8th inch cube, and 2½ feet of 1-16th inch, ending with 6 inches of 3-16th coal dust. The liquid is supplied continuously for 12 hours, with 12 hours rest, and the rate is 1,000,000 gallons per acre per day. The effluent is said to be bright and clear. He adds that "as a result of 12 months working the efficacy of the coal has increased. At first it would appear that the action is a chemical one, because the oxygen absorbed is at once directly affected; afterwards, however, nitrates are produced in considerable quantities, so that probably there is then a double action, chemical and bacteriological. The interior of the filter, after many months, has nothing but a slight earthy smell." This filter was introduced by Mr. Garfield in the summer of 1896.

Mr. Fowler, in his report of the Davyhulme experiments, in 1897, confirms the results of previous observers that coal and burnt clay filters, when worked continuously, rapidly become clogged, and that improved results are obtained with intervals for rest and aeration. He considers coal to be superior to burnt clay.

In the experiments with Manchester sewage the liquid dealt with was usually an effluent which had been treated with chemicals, such as lime and sulphate of iron or alumina, a procedure which robs the liquid of its natural bacteria, or inhibits their action. The work of bacteria is repeatedly recognised, and yet, even where, as at Accrington, Oldham, and other places, a treatment is adopted which is called biological, merely as a supplement to chemical and mechanical processes, we meet with such phrases as "Both the tank effluent and the cinder filtrate were tested for nitrites and nitrates practically without result" (Oldham); "There is practically no formation of nitrates in the filters at Swinton;" at Accrington, "nitrification in final filter *none*;" at Salford, "the large excess of lime present acts as a *temporary sterilising agent*." We cannot be surprised, therefore, that nearly all the effluents were found liable to subsequent putrefaction, or at the result that the anaerobic changes which had been suspended by the treatment, are resumed imperfectly and irregularly in the Ship Canal or the rivers.

In December, 1897, a Rivers Sub-Committee of the Manchester City Council visited representative sewage works at Barking, Friern Barnet, Sutton, Oldham, Swinton, Chorley, Glasgow, Salford, Hendon, and Accrington. In March, 1898, their report was approved and a deputation was appointed to wait on the Local Government Board. The conclusions of the Committee are shortly:—

1. That filtration by land is altogether impracticable.

2. That no practicable system of precipitation by chemicals alone has been laid before them which will meet the requirements of the Mersey and Irwell Joint Committee.

3. That the method most reasonably practicable and available is the biological filter or bacteria bed, such as may be seen in operation at many of the places visited.

After some delay and correspondence, two bacteria beds of coke breeze were completed at Davyhulme on September 14, 1898, under the superintendence of the three experts appointed—namely, Baldwin Latham, Percy F. Frankland, and W. H. Perkin, junr. The working capacity of each filter is 5,000 gallons, and the liquid to be purified is taken direct from the sewer and passed into a settling tank for an hour before proceeding to the first or coarse filter. After remaining in the latter for one or two hours, "according to circumstances," the partially purified sewage is transferred to the fine filter, where it again rests for a period of one or two hours. Each filter requires three-quarters of an hour for filling, and the same time for emptying. Samples are taken every five minutes during emptying, and mixed for analysis. The figures show, as in other cases, that an improvement occurs as the filters mature. At first, the beds were filled once a day with settled sewage and twice with crude, and under these conditions the capacity of the coke filter remained constant. With regard to trade refuse, Mr. Fowler reports that iron pickle (ferrous chloride), dye refuse, carbolic acid, and sulphocyanides from gas liquor, are all removed or oxidized, that "in no case has the presence of manufacturing refuse showed a marked tendency to make the purification less effective" (an opinion also shared by Dr. Perkin), though "it is probable that with purely domestic sewage the yield of nitrate would be larger."

The three experts also state in their report that "the bacteriological system, without the use of any chemicals, notwithstanding the peculiar nature of the Manchester sewage, will purify that sewage, and yield an effluent which will comply with all the requirements of the Mersey and Irwell Joint Committee, and will, in our judgment, be the means of greatly improving the waters of the Ship Canal."

The Local Government Board held an inquiry at Manchester, on January 12th and 13th, 1899, with reference to the application of the City Corporation to borrow £160,000 "for purposes of sewerage and sewage disposal." It was explained that Manchester had tried filtration by land and chemical treatment, but neither of these had been satisfactory. Eleven tanks had now been constructed at Davyhulme, each 300 ft. long by 100 ft. wide, and 6 ft. deep, with a united capacity of 12 to 15 million gallons, equal to half a day's dry weather flow. The population of Manchester was 520,000, and was increasing at the rate of 4,700 per annum. The tanks were originally used as chemical filters, the treatment and removal of sludge costing about £17,000 a year, the chemicals alone reaching £90 per week. It was then proposed to utilise these tanks for settling the raw sewage, which would subsequently pass through sixty acres of "double-contact" beds filled with coke breeze. An effluent would then be produced without the use of land, which would practically conform to the present requirements of the Mersey and Irwell Joint Committee. It is also stated that if the "double contact" did not suffice, they would employ a "third contact." The inquiry was adjourned for further details. The first contact beds of 30 acres were to be constructed of coarser material than the second 30 acres of second contact beds.

From a later report it appears that nitrification has at length been attained, the highest result being 0·68 of nitric nitrogen, but the average only reaching 0·27. In the Tables given they are called "double filtration" experiments, and as a fact they are neither anaerobic nor properly aerobic as the poor result in nitrification shows. Better results, as we shall see later, could probably be obtained by making the first filtration more anaerobic and by ensuring better aeration in the second filters. It will also be noticed that sedimentation in tanks is required by Manchester as essential for the proper working of the contact beds. This sedimentation, therefore, is the equivalent of the screening adopted by Mr. Dibdin, at Sutton, and the chemical precipitation of the earlier experiments before passing on to the one acre filter bed in the London County Council experiments.

[NOTE.—The adjourned inquiry was concluded on May 1st, 1899, when the experts gave satisfactory reports of the working of the experimental beds since January. On learning that the effluent was passed into the Ship Canal, the Local Government Board inspectors observed that "pending the report of the Royal Commission, the Board was not prepared to depart from what it has laid down as to the provision of land for the treatment of effluent." The Corporation have shown that 300 acres of land could be made available below the filter beds, if necessary.]

LECTURE III.—DELIVERED JANUARY 30, 1899.

Almost all of the processes for sewage treatment already described have been of a mixed or compound character, and not purely bacterial. And to a great extent this accounts for the numerous failures, either through expense, or irregular working, with such a variable liquid as sewage. Even when it was recognised that nearly all the destruction of effete matter was accomplished by minute organisms, there was a natural reluctance to trust entirely to the action of bacteria, from fear of the multiplication of pathogenic forms. Numerous attempts have consequently been made to sterilise sewage by chemicals, or heat, or electricity, or else to reduce the amount of solid matter by precipitants or filtration. The result of such treatment was a double product; first, an effluent, soon becoming putrid, owing to the subsequent inevitable entrance of more bacteria; secondly, a mass of sludge that required a further expensive treatment. The Royal Commission of 1882-84, after deciding against the discharge of crude sewage into any portion of the Thames, had prescribed "some process of deposition or precipitation, the solid matters to be applied to the raising of low-lying ground, or to be burnt, or dug into land, or carried away to sea." The latter course was resorted to as the only one that was thought available for London. In the case of towns like Bradford and others, at a distance from the sea, this course would be obviously impossible.

The one-acre filter at Barking is still only a part of a process that includes also the cost and complication of a preliminary precipitation, and a subsequent transport of the sludge to the mouth of the Thames. The mixture of chemical and mechanical treatment is even now in practice in a large number of places.

If we recall what was said in our first lecture as to the cesspool, it will be remembered that the natural process consisted in :—

1. Liquefaction of the insoluble matter, and modification of the dissolved matter, in a closed space, therefore mainly by anaerobic bacteria.

2. Oxidation afterwards by the help of aerobic bacteria during passage through a porous medium like land. We have seen how an active smaller area, such as that of a coke or ballast bed, can be substituted with economy and more regular working for at least a part of the necessarily large area of land.

I have always been of the opinion, and have often urged in previous papers, that the anaerobic change is an integral part of the preparation, and that the neglect, and even avoidance of it, has been a frequent cause of failure. As Rudolph Hering aptly remarks, "The aerobic process, when applied to organic matter in suspension, is slower than the anaerobic process. It takes a long time for solid particles of organic matter to disappear as such, when the conversion depends on the oxygen contained in the water. It takes a short time when it is brought about by anaerobes, which produce conditions causing liquefaction. The reverse seems true in the case of organic matter in solution, because the aerobic bacteria, and conditions favouring a thorough aeration of liquid sewage, will remove a much greater amount of organic matter from the water in the same time than if it is left to the action of anaerobes."

Therefore, the processes should be properly and systematically conducted in natural sequence. Any mixing or confusing in the order, any artificial interference, or attempt to work distinct reactions simultaneously in the same receptacle, will lead to uncertainty and irregularity in the results. I shall have again to revert in my last lecture to this principle of differentiated bacterial action. At present we have mainly to deal with the preliminary anaerobic liquefaction.

It has long been known that in the slow filtration of sewage, more particularly when the direction was upwards, so that little or no mixing with air occurred, very considerable changes in the organic matter were brought about, entirely unconnected with oxidation. Thus in an experiment of Frankland's as early as 1870, when a strong London sewage was made to traverse, "continuously upwards so as to exclude aeration," a layer of sand, the analysis of sewage and effluent given is the more instructive as the meaning of it was not understood at the time.

PARTS PER 100,000.

	Crude sewage.	Effluent.
Solid matters in solution........	64·5	80·5
Organic carbon	4·39	3·23
Organic N....................	2·5	1·4
NH_3	5·5	4·6
N as nitrites and nitrates........	None	·328
Total combined nitrogen	7·0	5·5

That is to say, the anaerobic bacteria have acted in the usual way :—

1. They have dissolved 16 parts per 100,000 of the solid matters or sludge, thereby increasing the solids in solution from 64 to 80.

2. Some of the ammonia has been changed into, almost certainly, *nitrite*.

3. 1·16 parts of carbon (25 per cent.) and 1·5 parts of nitrogen (60 per cent.) have been eliminated as non-ammoniacal gases, methane, N, and nitrogen oxides, with probably some CO_2.

We shall see later that this is exactly the process that goes on in the Exeter septic tank. In Frankland's filter the arrested suspended matter slowly disappeared just in the same way as organic substances do when dug into the ground or buried beneath the surface. The action at first is simply a process of *hydrolysis*, or combination with water, whereby the complex organic molecules of insoluble organic matters, like fibrin or cellulose, break up and dissolve as simpler compounds, with at the same time a liberation of much of the carbon and nitrogen in the form of various gases. And this first, or preparatory, stage, not only goes on without the presence of air or oxygen, but is actually hindered by it, that is to say, it is effected by the agency almost entirely of anaerobic microbes.

I find that a certain amount of confusion is likely to arise from the application of the words aerobic and anaerobic in two slightly different meanings—one with reference to the chemical changes that occur, the other with regard to the organisms that produce them. The words simply meaning "living with air," and "living without air," the chemist has applied the term "anaerobic" to changes occurring by life in which free oxygen took no part, simple changes by hydrolysis, or the addition of water, like that of urea into ammonium carbonate, of sugar into alcohol and CO_2, or of albumen or cellulose according to the anaerobic equations we shall presently meet. In this sense, the word "anaerobe" implies an organism that effects its changes in surrounding matter without oxidation. But a bacteriologist often uses the term, anaerobe, in the sense of "obligate anaerobe," *i.e.*, one that not only does not require oxygen, but is actually inhibited, or even killed, by its presence. The obligate anaerobes, as is shown by our table of bacteria in sewage, are, though exceedingly active, comparatively few. The "facultative" anaerobes on the other hand, those that can live either with or without oxygen, are much more numerous, as being the ones most suited to a liquid which contains little or none of the gas, but may at any time become oxygenated. Thus yeast, which was classed by Pasteur as "both an aerobian and an anaerobian," *i.e.*, as facultatively anaerobic—when in presence of excess of oxygen multiplies vigorously, but does not act as a ferment, whereas in sugar solutions containing no oxygen, it multiplies with less activity, but the fermentive character is most marked, the yeast attacking the sugar, and obtaining any oxygen it requires from it, or from the water present. Boussingault found that normal fermentation could be carried on *in vacuo*, and was greatly promoted by removing the CO_2 and alcohol as fast as they were formed, and thus preventing their retarding action. In the same way with bacteria, a better result is attained when the liquid products are continuously removed, as in the bacterial tanks of Cameron and Moncrieff, and the nitrifying trays of the latter, than where periods of stagnation occur, as in the intermittent system.

In a paper I read, published in the *Journal*,[*] I described in detail the chemical processes involved in the transformations, so far as they were known. As even now these are often not sufficiently kept in mind, I may recapitulate some of the main points, with a few later observations.

After remarking that the anaerobic changes occurred naturally in the mud-banks of estuaries, under the surface of the water of rivers, and at the bottom of stagnant pools, where the well-known "marsh gas" (mainly methane, CH_4) is produced, I observed that "in nearly all cases of destruction of organic matter this preliminary disintegration takes place before the final oxidation of the elements." I need hardly remind you that *hydrolysis*, or the breaking up of bodies by the action of water, is familiar in chemistry—and that it frequently results in the dissolving of matters previously insoluble, as in the conversion of starch or cotton fibre into dextrin and sugar, or of solid albuminoids like animal fibre or horn into various soluble products, with or without the assistance of acids, alkalies, or heat.

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

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[*] *Journal*, vol. xlvi., p. 81, December 17, 1897.

mediate neighbourhood, but also at a considerable distance, through the soluble ferments it forms and disengages. To most of them the termination "*ase*" is applied, as *diastase*, *glucase*, or generally *amylases*, which decompose starch; *lipase*, which hydrolyses fats; *cytase*, which dissolves cellulose, and probably numerous others, which are generated by organisms, and take part in the preliminary liquefying changes of sewage. For example, the enzyme (Rideal and Orchard, *Analyst*, Oct., 1897) produced by *Bacillus fluorescens liquefaciens*, when separated from the organism by a Pasteur filter, is capable of causing liquefaction of gelatine. Dr. Armstrong distinguishes between *zymosis*, or fermentation of organisms, and *enzymosis*, or change by enzymes or unorganised ferments. By the aid of the latter, bacteria are able to produce effects which are quite out of proportion to their size or even to their numbers. Enzymes are also developed by moulds and other fungi.

It must be repeated that these phenomena of resolution take place independently of the presence of oxygen and even more rapidly in its absence, and that even where the organic matter is partly converted into final stable oxidised compounds, the oxygen of the latter is not derived from the air, but is that which was originally present in the organic matter, or in the water taking part in the reaction.

I have previously instanced as a type of anaerobic hydrolysis, the case of albumen. Summing up all the changes in one equation, and taking the simplest empirical formula, we should have :—

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

giving us all the gases which are commonly met with in these decompositions, and *leaving no residue of solid matter*.

But the large amount of hydrogen that is liberated shows that there is an oxidation *at the expense of the oxygen of the water*. Thus I have found the gas evolved in the septic tank at Exeter to have the following composition :—

	Per cent. by volume.
CO_2	0·6
CH_4	24·4
H	36·4
N	28·6
	100·0

This is very similar to the fermentation described by Wood and Wilcox as produced by *Bacterium furfuris* in the manufacture of leather. This bacterium does not attack cellulose, but only starch and nitrogenous matter. They found a sample of the gas evolved to contain :—

CO_2 and traces of H_2S ..	25·2	per cent.
Oxygen	2·1	,,
Hydrogen	46·7	,,
Nitrogen	26·0	,,

Formic, acetic, butyric, and lactic acids were produced. These in sewage would combine with ammonia. I have lately found in a septic tank effluent salts of acetic, butyric and phenylacetic acids.

On the other hand, *Bacillus amylobacter*, which is strictly anaerobic, dissolves cellulose and evolves gases, the equation being given by Hoppe Seyler as—

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

The greater part of the carbonic acid remains dissolved as carbonate of ammonia, while the hydrogen, from its easy diffusibility, escapes from the tank more rapidly than the heavier gases. No sulphuretted hydrogen was found in the septic tank gases, the sulphur remaining in solution mainly as methyl mercaptan, $CH_3\ HS$. The normal decomposition of urea into carbonate of ammonia and water is an example of a simple hydrolysis which produces no free gas, thus :—

$$CH_4\ N_2O + 2H_2O = (NH_4)_2\ CO_3.$$

The following Table shows the weight of oxygen required to convert some typical organic compounds into the final products that are actually found :—

Substance.	Empirical formula.	Per-centage composition.				Oxygen required by one part to convert it into—	
		C	H	N	O	CO_2, H_2O, & N	CO_2, NH_3, & H_2O
Albumin	$C_8H_{13}N_2O_3$?	53·4	7·1	15·8	23·7	1·754	1·48
Gelatin	—	50	6·6	15·3	25·1	1·61	1·33
Starch, cellulose, and woody fibre	$C_6H_{10}O_5$	44	6·2	—	49·4	1·184	1·184
Ammonium amidoacetate (Ammonium salt of glycocine)....	$C_2H_8N_2O_2$	26·1	8·76	30·43	34·78	1·043	0·53
Urea	CH_4NO_2	20	6·7	46·7	2·66	0·803	0·

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

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

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

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

The "cesspool" or anaerobic preliminary treatment is however by no means novel, as it is on record that an early attempt was made in France to carry out systematically this form of treatment. Rudolph Hering has given an abstract of an article in the "Cosmos. Les Mondes" of December, 1881, and January, 1882, on the "Mouras Automatic Scavanger," described as a "mysterious contrivance," which has been used for 20 years, or since 1860. It consists of a closed vault with a water seal, which "rapidly transforms all the excrementitious matter which it receives into a homogeneous fluid, only slightly turbid, and holding all the solid matters in suspension in the form of scarcely visible filaments. The vault is self-emptying, and continuous in its working, and the escaping liquid, while it contains all the organic and inorganic elements of the fæces, is almost devoid of smell, and can be received into watering carts for horticultural purposes, or may pass away into the sewer for use in irrigation." As to the theory of the action, it is said, "May not the unseen agents be those vibrions or anaerobies which, according to Pasteur, are destroyed by oxygen, and only manifest their activity in vessels from which air is excluded"?

Observations with a glass model showed that "Fæcal matters introduced on August 29th were entirely dissolved on September 16th, while even kitchen refuse, onion peelings, &c., which at first floated on the surface, descended after a time and awaited decomposition. Everything capable of being dissolved acted in a similar way, and even paper wholly disappeared."

It is further said, "The principle on which M. Mouras bases the action of his machine are that the animal dejecta contain within themselves all the principles of fermentation or of dissolution necessary and sufficient to liquefy them, and to render them useful in their return to the soil, and without appreciable loss."

A later article of January, 1883, by the Abbé Moigno gives formulæ for the dimensions of the tank, estimating its superficial area as preferably 1-10th metre, or about 1 square foot per person. The Exeter tank, I may remark in passing, works out to about 0·6 square foot per person. The article also specifies that "for the complete solution of the floating solid matter a period of thirty days should be allowed," giving

$$\frac{1 + 2 + 3 + \ldots\ldots 30}{30} M.$$

as the the total average amount of suspended matter present in the tank at any instant when M is the weight of organic matter present in the volume of sewage dealt with per day. The size of the tank required is therefore not so large as to be impossible with sewages containing an ordinary amount of organic matter, but as the effluent from such a tank without further nitrification has practically all the properties of liquid sewage, it probably accounts for the fact that the "Automatic Scavenger" did not attract more general attention at the time. Mr. Scott-Moncrieff's early experiments seem to have originated from his observation of the rapid liquefaction of organic matter in long lengths of sewers. He began on a practical scale in 1891 by constructing at Ashtead a bacterial tank into which the crude sewage was admitted from below and gradually passed upwards over the surfaces of a bed of stones. He found that the liquefaction of the solids was so effective that the whole sludge of seven years from a household of ten persons was absorbed on nine square yards of land, causing no distinction in appearance between this soil and that surrounding. The space beneath the under grating of the tank had a capacity of less than five cubic feet, and would obviously have filled up in a short time but for the liquefying action that had taken place.

In 1892 his process was examined by Dr. Houston, and later by Dr. Sims Woodhead and myself. Dr. Houston's report of 1893 is practically the first literature on the purification of sewage as a whole bacteriologically, without deposition or chemicals and with hydrolysis by micro-organisms of the grosser organic matter as a prelude to further treatment, a point which is not mentioned in the Massachusetts reports.

In this way the difficulty of the production of sludge was completely disposed of. I have shown how a great part of this, during or after liquefaction, disappears as gases. It is obvious, however, that the remaining liquid will retain the ammonia which has been produced by the hydrolysis, together with residues of nitrogenous and carbonaceous dissolved matters, so that judged by ordinary standards of analysis, this liquid, in the first stage, will show somewhat large amounts of carbon and nitrogen. As examples of some effluents from Moncrieff's anaerobic tanks, derived from heavy domestic sewages during the early stages of experiments, I may quote the following analyses made by C. G. Groves for the Thames Conservancy, and by myself:—

PARTS PER 100,000.

Date.	Analyst.	Suspended matter.	Dissolved solids.	Cl.	Ammonia.	Albuminoid NH_3.	Oxygen consumed.
May 7th, 1895	Groves.	Trace.	101·0	10·4	15·0	0·8	5·4
June 1896	Groves.	,,	112·0	21·0	7·0	0·8	3·9
July 1897	Rideal.	,,	191·5	59·4	9·0	0·7	8·2

With reference to the first sample, Groves remarks that it contains *a large amount of easily decomposable nitrogenous organic matter in solution.* This great instability of the organic compounds that come over from cultivation tanks is the principal feature of the process.

With the object of obtaining an oxidized effluent, Moncrieff then duplicated the tanks and used them alternately with periods of aeration and rest. The effluent obtained was clearer, and had less odour, but showed practically no nitrification. That the liquid was ready for natural oxidation was shown by the fact that when at Towcester in 1893, the effluent was passed into a small brook, the water actually became clearer below the discharge than above it. Efforts were then directed towards carrying on this final change within the apparatus. It was first tried to obtain nitrification by passing the effluent through the "nitrifying channels," consisting of half drain pipes joined in line by cement, and filled with coke. But the result was not commensurate, for the reason that the right organisms were not developed. During the transit, the liquid was largely exposed to the light, whereas it is known that the bacteria forming nitrates thrive best in the dark. It was noticed that denitrifying organisms, which are not so sensitive, had actually in some cases reduced existing nitrates, as pointed out by Dr. Houston in the Ashtead experiments. How the difficulty was afterwards overcome by the construction of the nitrifying trays will be described in the last lecture.

Up to this point there was still a belief that hydrolysis and aerobic nitrification could be carried on successfully in the same tank. At Aylesbury air was forced in by a steam jet, with this object in view, but the result was unsatisfactory.

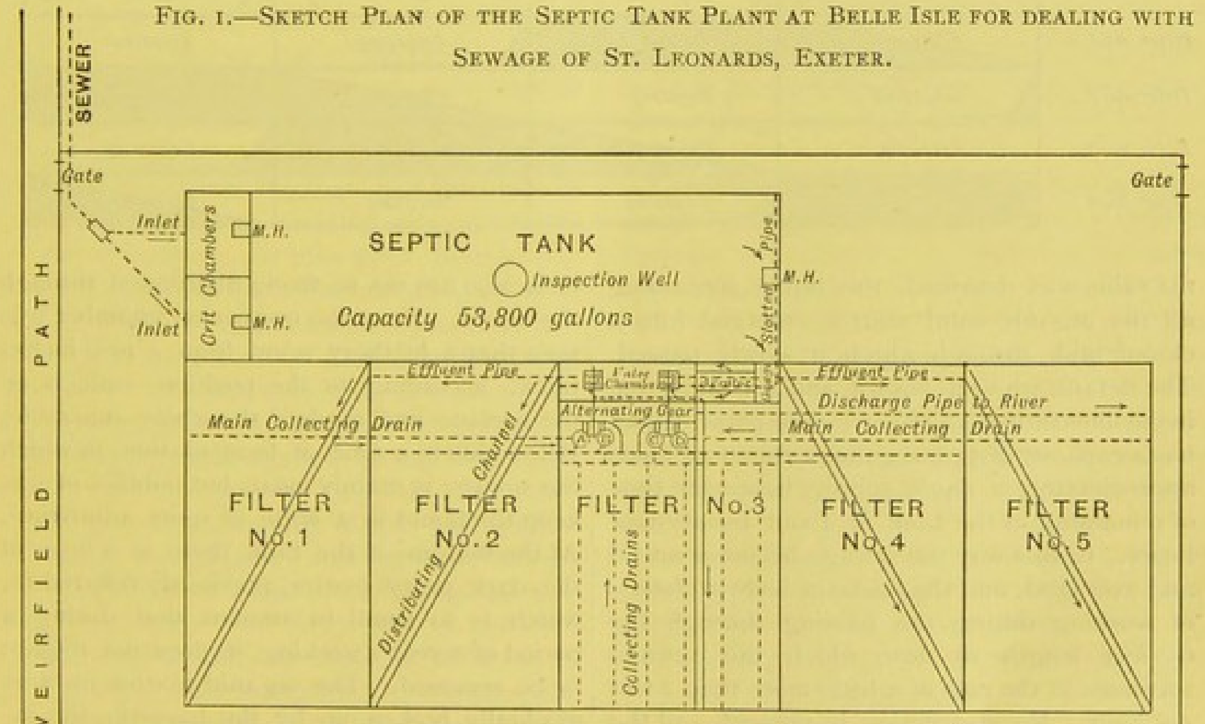
It was concluded finally that all the nitrogenous organic matter must be as far as possible broken up into ammonia before being oxidised to nitrates, and that these two reactions should be carried on in separate areas, the one under anaerobic conditions, and the second with free admission of air but not of light, when the distinctly nitrifying bacteria should be free to work without being interfered with by conditions favourable to other organisms, or by these latter organisms themselves. In very strong sewages there seems almost no limit to the capacity of the hydrolytic ferments to break down nitrogenous matter into ammonia. Thus Marchal found that one of the organisms that effects this function, *B. mycoides*, could thrive in a medium containing two parts in a thousand of caustic potash, equivalent to 660 parts per 100,000 of free ammonia, and in septic effluents in the first stage I have found as much as 30 to 40 parts per 100,000 of NH_3.

But it was found, on the other hand, that there was a limit to the amount of anaerobic change if nitrification is to be carried to a successful issue.

Thus, in recent experiments at Caterham, dealing with a heavy sewage containing 18 parts of Cl per 100,000—the entire discharge from the barracks—the preliminary process was pushed much further than usual, to try if it were possible to carry the anaerobic fermentation too far, with the object of ascertaining the most favourable point, by estimating the free ammonia, and finding what amount gave the best results in nitric nitrogen. Exceptionally anaerobic conditions were introduced, by means of inverted open-mouthed glazed earthen vessels, about 400 in number, piled in a tank 20 ft. by 10 ft. by 9 ft. deep, and kept down by weights. Each pot became filled with gases of the character I have described, devoid of oxygen, so that there were a large number of surfaces on which zooglœa colonies of bacteria could quietly develop in contact with the percolating sewage. The result was an effluent containing 126 parts per 100,000 of dissolved solids, 35 of free NH_3, and 5·3 of organic nitrogen. The liquid was now highly toxic to any but anaerobic organisms, and absolutely refused to nitrify. When diluted, however, with a few volumes of natural water it rapidly became purified.

In 1895, Mr. Cameron, City Surveyor of Exeter, introduced his "septic tank" process for the treatment of a portion of the sewage of the city, comprising about 2,000 persons, on the combined system, yielding about 50,000 gallons of sewage. After passing through a grit chamber where gravel brought down by

Fig. 1.—Sketch Plan of the Septic Tank Plant at Belle Isle for dealing with Sewage of St. Leonards, Exeter.



Area of each filter, 80 square yards; and depth 5 feet = volume 22,500 gallons.
Effluent introduced at start = 0·6 of above volume ∴ 0·4 of original volume = coke.
Effluent introduced in ordinary working from 8,000—9,000 gals. per filter.
A, B, C, D are collecting wells, receiving filtered water from the four filters in use.
By means of the alternating gear, each filter in rotation is filled, discharged, and aerated automatically.

FIG. 2.

Cycle for Four Filters, Nos. 1, 2, 3, *and* 4, *Discharging into Four Collecting Wells,* A, B, C, *and* D.

At starting, let filter No. 4 be already full and resting, and No. 1 filling.—Period I.

When No. 1 fills, it overflows into tipper C, discharging No. 4, putting down outlet valve of No. 3, and admitting effluent to No. 3.—Introducing Period II.

When No. 3 fills, it overflows into tipper B, discharging No. 1, putting down outlet valve of No. 2, and admitting effluent to No. 2.—Introducing Period III.

When No. 2 fills, it overflows into tipper D, discharging No. 3, putting down outlet valve of No. 4, and admitting effluent to No. 4.—Introducing Period IV.

When No. 4 fills it overflows into tipper A, discharging No. 2, putting down outlet valve of No. 1, and admitting effluent to No. 1.—And so on.

Diagram of Overflow Pipes.

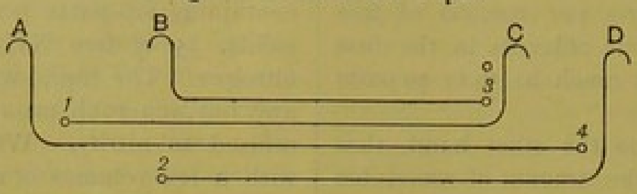
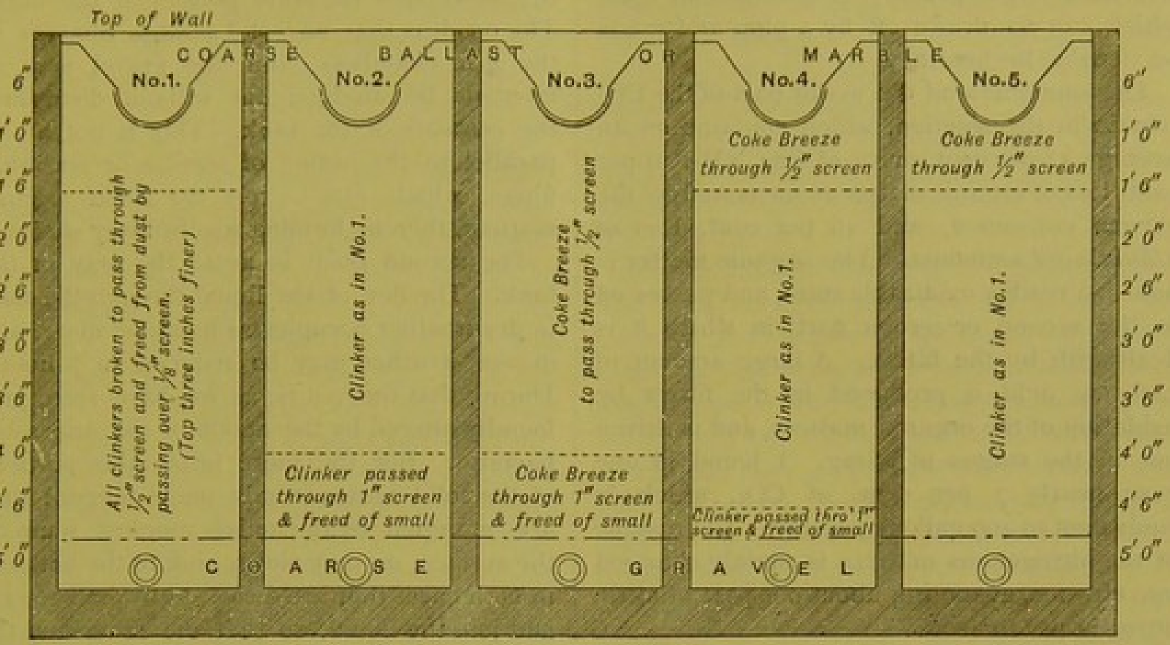


Diagram showing
successive states of Filters corresponding to successive positions of alternating gear:-

	PERIOD I.		PERIOD II.		PERIOD III.		PERIOD IV.	
Position of Gear	A B C D	*C Tips*	A B C D	*B Tips*	A B C D	*D Tips*	A B C D	*A Tips*
Filter No. 1	*Filling*		*Resting Full*		*Emptying*		*Aërating*	
Filter No. 2	*Emptying*		*Aërating*		*Filling*		*Resting Full*	
Filter No. 3	*Aërating*		*Filling*		*Resting Full*		*Emptying*	
Filter No. 4	*Resting Full*		*Emptying*		*Aërating*		*Filling*	

the rains was detained, the liquid containing all the organic solid matter emerged into a closed tank, through which it slowly passed. The details are well known and are indicated in the illustrations. (Fig. 1.) The present tank has a capacity of 53,800 gallons, therefore holds approximately a day's supply, hence the time of remaining in the tank is about twenty-four hours. In this way the sewage becomes mixed and averaged, and the bacteria have a chance of working during the passing through the 65 feet length of flow, which the sewage traverses at the rate of a little more than 2 feet per hour. No obstruction is present, and the entire space is available, differing from what we have seen of tanks partially filled with stones or coke. In the latter the dimensions must either be larger in proportion, or the sewage must pass at a greater rate, the bacteria also are not so freely distributed through the liquid. From the inspection chamber it is seen that a leathery scum from 2 to 6 inches thick, according to the position, collects on the surface and renders the whole anaerobic. Below this is a zone of fermentation, in which the sewage is mainly clear, but bubbles of gas keep the liquid in a state of quiet admixture. At the bottom of the tank there is a layer of the dark peaty matter, previously referred to, which is so small in amount that during a period of a year's working, it does not require to be removed. The organic matter in it is gradually broken up by the bacteria, the inorganic matter is raised by the gases and gradually carried off in the flow, so that its quantity does not sensibly increase. On October 13th, 1898, I found this peaty matter to contain about 68 per cent. of mineral,

Fig. 3.—Section Showing Arrangement of Filtering Material at Belle Isle.



32 per cent. of organic matter, and 2·4 per cent. of nitrogen.

According to Adeney's researches it seems to be necessary for the subsequent nitrification.

The flow through the tank is continuous, therefore requires no attention for Sundays or night. The inlet and outlet are submerged so as to minimise the disturbance of the contents. At the far end of the tank a transverse iron pipe, about a foot below the level of the liquid, with a slot on the under surface extending its length, forms an exit for the effluent, which passes over a V-gauge, and then falls in a thin stream over an aerating weir, to restore aerobic conditions. It then flows through distributing channels on to filters of coke breeze or clinker similar to those at Barking and Sutton, four of which are used at a time, and one kept in reserve. An automatic gear devised by Mr. Cameron regulates the cycles of filling, resting full, emptying, and aeration, so that here again no attention is required. (Fig. 2.) The Local Government Board inquiry of 1897 approved of the system being applied to the whole of the city, of a population of 46,000, with the usual proviso as to land. The daily flow is 1,064,610 gallons, and for this, six tanks 181 ft. by 35 ft. by 7 ft. deep, with a capacity of 262,422 cubic feet, will be provided, in which the suspended solids will dissolve. Eight filters of a total area of 2½ acres, or 13,600 sq. ft. each, having a depth of 3½ ft. of crushed furnace clinker on 6 in. of coarse gravel, and a working capacity of 2½ million gallons a day, operating with the alternating gear as before, will deal with the tank effluent. (Fig. 3.)

It will be seen that Mr. Cameron, like Mr. Scott-Moncrieff, carefully differentiates between the hydrolytic or solution process, and the subsequent oxidation required for final purification. Dr. Sims Woodhead has shown that while the anaerobic organisms are more numerous in the tank, a number of liquefying aerobic organisms are still present, and increase on passing over the aerating weir. The filters are, of course, aerobic.

The changes occurring in the tank are rather complex. Analyses were made by Dupré, Perkins, and myself, in 1896 and at subsequent dates, and by Dibdin and Thudichum, and Pearmain and Moor, in 1897. From these it appears that the total dissolved solids are increased somewhat, but not in relation to the organic *débris* that has passed into solution. A large proportion has undergone the hydrolytic decomposition which we may represent in two forms :—

1. Producing nitrogen, methane, a small quantity of hydrogen and carbonic acid, as in the general equation already given :—

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

2. Producing ammonia, CO_2, and a large quantity of H :—

$$2\ C_8H_{13}N_2O_3 + 16H_2O = 4NH_3 + 16CO_2 + 33H_2.$$

Both species of reactions go on simultaneously, along with others, according to the species of bacteria. The result is the production of a large quantity of inflammable gas, which can be drawn off by a pipe and made serviceable for heating.

The ammonia and the major part of the CO_2 remain in the solution, which contains on an average 33 per cent. more of free NH_3, 29 per cent. less of organic matter as measured by the oxygen consumed, and 46 per cent. less of *albuminoid* ammonia. The organic matter is now in a readily oxidizable state, and passes on to the second or aerobic part, in which it is dealt with by the filters. A large amount of carbonic acid is produced in the filters by oxidation of the organic matters, and is driven out in the stages of filling. I found in one case nearly 7 per cent. of CO_2, which is equivalent to 400 gallons per day. The residue of the nitrogenous matters is mainly changed into nitrates, averaging about one part of nitric nitrogen per 100,000.

The following Table shows the per-centage purification produced by the Exeter process, as stated by different observers at the inquiry in 1897, measured by the reduction of albuminoid ammonia and of the oxygen consumed :—

	Albuminoid NH_3.	Oxygen consumed.
Dupré	84·9	88·3
Perkins	64·4	78·7
Dibdin and Thudichum....	63·2	80·9
Pearmain and Moor	80·0	90·0
Mean	73·6	84·0

My own figures for the separate stages of purification, published in 1896, were, in per cents. of the crude sewage :—

	Albuminoid NH_3.	Oxygen consumed.
By tank	46	29
By filters	31	53
Total	77	82

The installations at Yeovil and other places have proved that the septic tank process is not affected by manufacturing refuse. The smoothing and diluent effect in the volume of sewage, and the room for precipitation and neutralisation by the ammonia, seem to obviate these difficulties.

Three other points in the Exeter Local Government Board inquiry require comment. One was the action of the grit chamber. On entering this the heavy particles of gravel and sand at once sank, while the organic refuse, which in fresh sewage always floats, passed over the submerged wall, 7 feet from the entrance and 12 inches below the surface of the liquid, into the main portion of the tank. The result is that no solid sewage remains in the grit chambers, and the gravel may at intervals be dredged out without disturbing the contents of the tank. This is not at all parallel to the action of screens or straining filters, which also arrest the solid organic matters, thereby forming a subsidiary sludge.

The second point is as to the stay in the tank. The flow of the liquid through the tank in dry weather occupies 24 hours or more, and in wet weather may be reduced to 7 hours. During that time, it is, as we have seen, profoundly altered by the action of the anaerobic bacteria. But the more intractable portions of the solid matter remain much longer : they are entangled by the active zooglœa scum on the surface, or may slowly sink to the bottom : in both cases they are dissolved by the bacteria and join the liquid, so that the scum and the sediment, though showing some fluctuations, remain about the same volume.

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

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

With intermittent fine bed filters following coarse bed or chemical treatment, as at Leeds and London, fish have lived in the filtrates. At Exeter, Dr. Cartwright Wood examined the tank effluent, the filtrate, and the river water before and after admixture. The broth inoculated with these fluids, and incubated for 48 hours, had no effect upon rabbits or guinea-pigs, when 2 c.c. were injected subcutaneously.

When incubated for 11 days, the tank effluent and the water at Belle Isle contaminated with the untreated town sewage, were found to be morbific, but the filtrate and the water at Salmon Pool weir, some little distance below the town, contained so little morbific material of any kind, that even with this severe test both animals remained alive and perfectly well.

Dr. Woodhead, in his report, concludes "that none of the organisms themselves found in the tank effluent are capable, in the quantities present or in which they can grow even in broth, of setting up any morbid changes."

With regard to typhoid fever, Lawes and Andrews some years ago showed that some liquefying organisms have a germicidal effect upon typhoid bacilli, so that their sojourn in a septic tank or their arrest in an anaerobic upward filter, with such organisms diminishes instead of increases their chance of survival. Dr. Pickard, of Exeter, has proved this fact again experimentally by introducing an emulsion of the typhoid bacilli into a septic tank, when he found that instead of increasing they rapidly diminished, until after 14 days less than 1 per cent. of the number introduced were surviving. The same investigator also proved that the filtration was also efficient in removing typhoid bacilli, as he found that filtration as conducted at Exeter removed about 90 per cent. of typhoid bacilli from sewage inoculated with this organism. The passage of a tank effluent containing no typhoid through the same filter yielded filtrates containing only about 1 per cent. of the bacilli introduced in the first filtration, showing that the environment was unsuitable for their development, even if their absence from the filtrate was due partly to a straining action.

Dr. Houston with the Ducat filter has shown that from sewage containing one *B. coli* per 100,000 c.c. a filtrate is obtained which contained in this quantity no colonies resembling this organism. And that sewage containing between 1,000 and 10,000 spores of *B. enteritidis sporogenes* per c.c., retained after filtration less than 10 per c.c., whilst the aerobic bacteria causing liquefaction of gelatin were likewise reduced from 22 to less than 1 per unit.

In my own work I have proved that the spores of *B. enteritidis sporogenes* survive, as might be expected, the septic tank treatment, but Houston has shown, as stated above, that 99 per cent. can be removed if the tank be followed by a well aerated filter.

Before this evidence of the comparatively innocuous character of the filtrates from bacterial systems was available, I pointed out that subsequent chemical treatment could be used for sterilising the filtrate if necessary. Such reagents as may be conveniently employed may be called "finishers," as the resulting purified sewage is satisfactory, both from chemical and bacterial points of view. Chlorine is one of such reagents, and the late Dr. Kanthack has established the fact that with one grain to four gallons of the tank effluent, or to five gallons of filtrate, with a period of contact of about five minutes, the number of bacteria can be reduced from any number (even millions) to 10-50 per cubic centimetre, and that no pathogenic organisms were found in any of the numerous samples of Maidenhead sewage finished in this way. I found at the same inquiry that on adding 1·77 parts of available chlorine per 100,000, although about half the amount immediately combines with any organic matter present, if the aerating filter has not worked efficiently, the micro-organisms, by contact with the remainder, are gradually killed, so that plate cultivations of such sewage taken after 14 minutes showed no growth with three and a half days' incubation.

Lecture IV.—Delivered February 6, 1899.

There is an early part of the transformation which we have not hitherto noticed. When fæcal and other solid matters are first discharged, the earliest changes must be aerobic, because of the free oxygen dissolved in the water and contained in the air. The effect is mainly the same as the *last* stage, *i.e.*, the organisms acting in a normal manner upon those simpler constituents like ammonia, which must obviously already exist in small quantities, and into which the process itself afterwards resolves the main ingredients of the sewage. Nitrates in small quantities are consequently often observed in discharges which are moderately fresh.

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

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

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

The phenomenon of *symbiosis*—that is when one or more kinds of bacteria act together and effect decompositions which neither of them could do separately—shows that it is not necessary to aim at securing individual species, which indeed would be impossible in practice, if the complexity of the flora of sewage be considered.

Dr. Sims Woodhead found in Exeter crude sewage the following number of organisms per cubic centimetre (about 20 drops):—

Anaerobic	Liquefying, 300,000 (some fluorescing and many of them gas-producing). Non-liquefying, 700,000.
Aerobic (facultatively anaerobic)	Liquefying, 500,000. Non-liquefying, 3,000,000 to 5,000,000.

Dr. Houston, in London sewage, finds about 4,000,000 to 5,000,000 of bacteria, of which about 500,000 are liquefying.

On the other hand, in a mixture of species, some are crowded out, and being unable to act, finally disappear. Such is the fate, as we saw in the last lecture, of pathogenic organisms, which preferably grow at blood heat, and do not find themselves under favourable conditions at low temperatures, and among a swarm of competing others.

If, however, successive zones or habitats be arranged under slightly varying circumstances of aeration or otherwise, groups of species will establish themselves to the exclusion of others, and sewage passing through will find itself exposed to a natural cycle of change. Such an arrangement takes place in the top and bottom layers of the septic tank, and still more in the "bacteria tank" of Scott-Moncrieff, where the stones become coated with zooglœa layers of different organisms at successive points. The same system he carries out further in the oxidising filter, to be described later.

This differentiation of the organisms leads us to a consideration of the chemical reactions that occur, and the bacteria which produce them.

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

1. The solution and decomposition of albuminous bodies.
2. The fermentation of urea.
3. The fermentation of the amido-compounds formed from the albuminous bodies.
4. The formation of organic acids, and the fermentation of their salts.
5. Cellulose or methane fermentation.
6. The hydrolysis of carbohydrates.

7. The formation of small quantities of sulphur compounds, like H_2S, mercaptan, &c. This, from the odour of the products, often attracts the most attention.

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

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

BACTERIA OCCURRING IN SEWAGE.

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

Obligatory Anaerobes.

Spirillum rugula, L (very active, spore bearing, gives rise to a fæcal odour).

Sp. amyliferum (in absence of air acts as a vigorous ferment).

Bacillus enteritidis sporogenes. (Klein. See Lecture I.)

B. amylobacter, L *(Clostridium butyricum)*.

B. butyricus (Botkin), L (gives much gas).

(*B. subtilis* is aerobic, and rapidly consumes oxygen, so is dormant in the first stage.)

Facultative Anaerobes or Aerobes.

B. putrificus coli, NL (decomposes albuminous substances with liberation of ammonia, whether air is present or not).

Spirillum plicatile, serpens, undula, tenue, and *volutans*.

Vibrio saprophilus, aureus, flavus, fluorescens, NL (in sewer mud).

B. mycoides, L
Proteus vulgaris, L } Produce NH_3 from nitrogenous organic matter, and denitrify.

B. fluorescens putridus (similar, produces trimethylamine).

B. fluorescens liquefaciens, L, and *non-liquefaciens*, NL. See Lecture I.

Micrococcus ureæ, NL; *B. ureæ*, NL (convert urea into ammonium carbonate, the latter the most energetically). Flügge has also described a *M. ureæ liquefaciens*.

B. mesentericus, L (several varieties in London crude sewage).

Proteus mirabilis and *Zenkeri*, L.

B. megaterium, L; *liquefaciens*, L; *magnus, spinosus*.

Streptococcus liquefaciens coli, L, and *mirabilis*, NL.

B. saprogenes, I., II., III.; *pyogenes* and *coprogenes fetidus*.

B. acidi paractici.

B. lactis aerogenes, NL (produces CO_2 and H).

B. coli communis, NL (produces much gas, mainly H).

Cladothrix dichotoma, L.

Proteus sulphureus, L (produces H_2S and mercaptan).

Bacterium sulphureum, L (liquefies gelatine and casein, produces H_2S). Found by Sims Woodhead in Exeter sewage.

Beggiatoa alba (secretes granules of sulphur, formed, according to Winogradsky, by oxidation of H_2S, and finally turned into sulphuric acid by the plant).

The following forms reduce nitrates to nitrites :—
B. vermicularis, liquidus, ramosus, aquatilis (grows luxuriously in ammonia solutions), besides *mycoides* and *Proteus vulgaris*.

The following were found by Jordan in the sewage of St. Lawrence, Massachusetts :—*B. cloacæ*, L; *ubiquitus*, NL; *reticularis*, SL; *circulans*, L; *hyalinus*, L: all reducing nitrates. *B. superficialis*, SL, not reducing.

I must content myself with a few comments on some of the species. First, we must notice that as sewage contains little or no oxygen, nearly all these species must be at least facultatively anaerobic, and the decompositions they engender are hydrolytic. Consequently it is a mistake in the first stages to introduce air, which merely hinders the anaerobic changes. Any attempt to induce early nitrification before solution is effected, results in the production of nitrites and not nitrates.[*] The same non-recognition of anaerobic liquefaction leads to the difficulty with the solids blocking the filters, and to the compulsory resort to screens, sedimentation, or even to an idea of preliminary precipitation, all of which produce their equivalent of sludge. During the "resting full" period of the filters the changes are really anaerobic, during emptying and resting empty the aerobic bacteria are at work. Therefore if sole dependence is made on such filters, the process is a mixed and variable one, and the result is shown in deficient nitration.

The Vibrios in sewer mud do not liquefy gelatine, but act probably on the carbonaceous vegetable matter.

Bacillus ureæ is said to be more energetic in converting urea into ammonium carbonate than the associated *Micrococcus ureæ*.

The putrefactive fermentation of albuminous bodies is caused by a large number of species, of which the forms from London sewage, mentioned in the first lecture, are among the most frequent. The first action is parallel to ordinary digestion, that is the so-called *peptonization*, or conversion into a soluble form. The peptones are then split up, amido-acids like leucin, tyrosin, &c., are formed together with a number of substances of the aromatic group,[†] the amido-acids further break

---

[*] *Bacillus mycoides, liquidus, vermicularis, ramosus, cloacæ* (Jordan) *aquatilis*, and others powerfully reduce nitrates to nitrites, and account for the absence of nitrates in sewage.

[†] Oscar Emmerling found that *Streptococcus longus*, in liquefying fibrin, produced peptones, and then ammonia,

TABLE OF FERMENTATION OF ORGANIC ACIDS.

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

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

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

up into fatty acids and ammonia. Tyrosin yields indol, skatol, phenol, and acids related to benzoic (*Spirillum rugula* and the *B. coprogenes* group develop a strong fæcal odour, probably owing to this reaction).

The breaking up of organic acids is described in the annexed Table, adapted from a summary of the varieties of septic fermentation, by Dr. E. Herfeldt, of Bonn.*

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

In a septic tank effluent I lately found, by fractionation of the hydrochlorides :—

---

mono- and tri-methylamine, tyrosine, leucine, fatty acids to caproic (except valeric), succinic, and a collidine, or pyridine derivative (Berichte, 1897, xxx, p. 1863).

* "Centralblatt fur Bakt.," Jan. and Feb., 1895; "Journ. Soc. Chem. Ind.," May, 1895.

	Parts per 100,000.
Actual ammonia	3·48
Monomethylamine, CH_3NH_2	0·844
Trimethylamine	traces

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

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

1. Their volatility and odours;
2. Their removing carbon as well as nitrogen;
3. The toxic nature of some to the organisms of nitrification. Therefore—

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

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

The same remarks apply to:—

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

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

Anaerobic fermentation is called by the Germans *true putrefaction* (Faulniss), while aerobic is termed *mouldering* (Verwesung). In the first, hydrolytic processes, in the second oxidation, prevail.

Dissolution of Cellulose and Fibrous Matters.

Mitscherlich in 1850 proved that cellulose was dissolved by fermentation, and Van Tieghem in 1870 describes the most active organism as *B. amylobacter*, anaerobic, and derived principally from the intestines of animals. Tappeiner fermented cotton-wool and paper-pulp in a weak nitrogenous solution, and obtained CO_2 and methane in neutral, and CO_2 and H in alkaline solution. Hoppe-Seyler in 1886 found only traces of soluble residues, and concluded that at first a soluble carbohydrate was formed by the action of water, and that this was then split up into carbonic acid and methane—

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6$$

$$C_6H_{12}O_6 = 3\,CO_2 + 3\,CH_4$$

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

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

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

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

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

1. They set up acid fermentation and corrode iron.
2. Many of them (*e.g.* cabbage leaves) contain sulphur compounds, and evolve very offensive odours.
3. They form a pulp which blocks the strainers.

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

FERMENTATION OF OTHER CARBOHYDRATES.

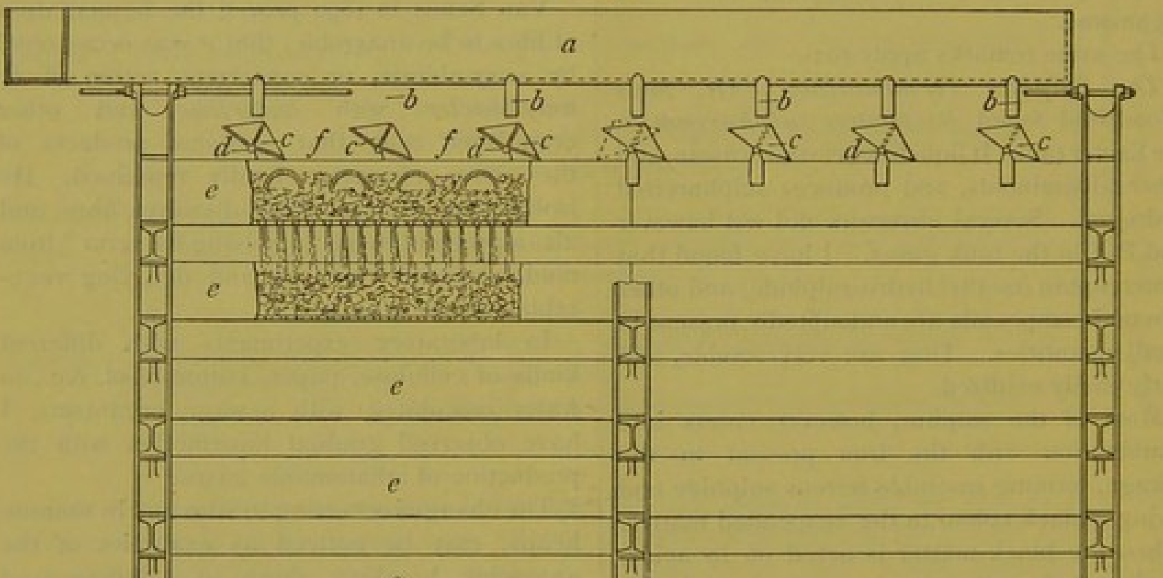
Starch, different sugars, and gummy substances undoubtedly enter into sewage. But their hydrolysis is so rapid, that very little trace of them is found after a short period. Those fermentations, like the alcoholic, which are occasioned by higher fungi like yeasts and moulds, do not present themselves. The changes are mostly lactic, by *B. acidi lactici;* or butyric, by *Clostridium butyricum* or *Bacillus butyricus* (both anaerobic), giving, besides the respective acids, carbonic acid, hydrogen, and water.

DECOMPOSITION OF FATS.

Soap-suds and greasy matters give rise to considerable trouble in the mechanical treatment of sewage. At Bradford the refuse of wool-scouring has been the chief difficulty for years. The sewage has been precipitated chemically by ferric sulphate, but, in addition to the large quantity of chemicals required, and the unsatisfactory character of the effluent, the very large quantity of grease in the sludge obstructs the filter presses, and renders it impossible to reduce the water below 95 or even 98 per cent., which not only increases its weight and bulk, but also the difficulty of drying. The Corporation will eventually follow the example of Leeds, and adopt a bacteriological method.

In a bacterial tank the grease is first emulsified by the ammonia. There are several bacteria that attack fats in presence of nitrogenous substances (Sommaruga, Zeits. Hyg., xvii. 441), breaking them up into the simpler acids of the fatty series, like acetic and butyric, which in their turn are finally resolved into CO_2 and H. Many common moulds also act on fats, notably the ordinary green mould, *Penicillium glaucum*, which Hanriot found to contain an enzyme "lipase," besides emulsine and other ferments. Moulds are not commonly present in the anaerobic stage, but occur in the second, or limited aeration. Ritthausen and Baumann found that a great destruction of fat occurred by the action of moulds and bacteria in a substance containing proteids as well; the substance they experimented on was rape-cake.*

FIG. 4.



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

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

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* "Landw. Versuchs. Stat.," xlvii. 389, 1896. The subject does not seem to have been much investigated.

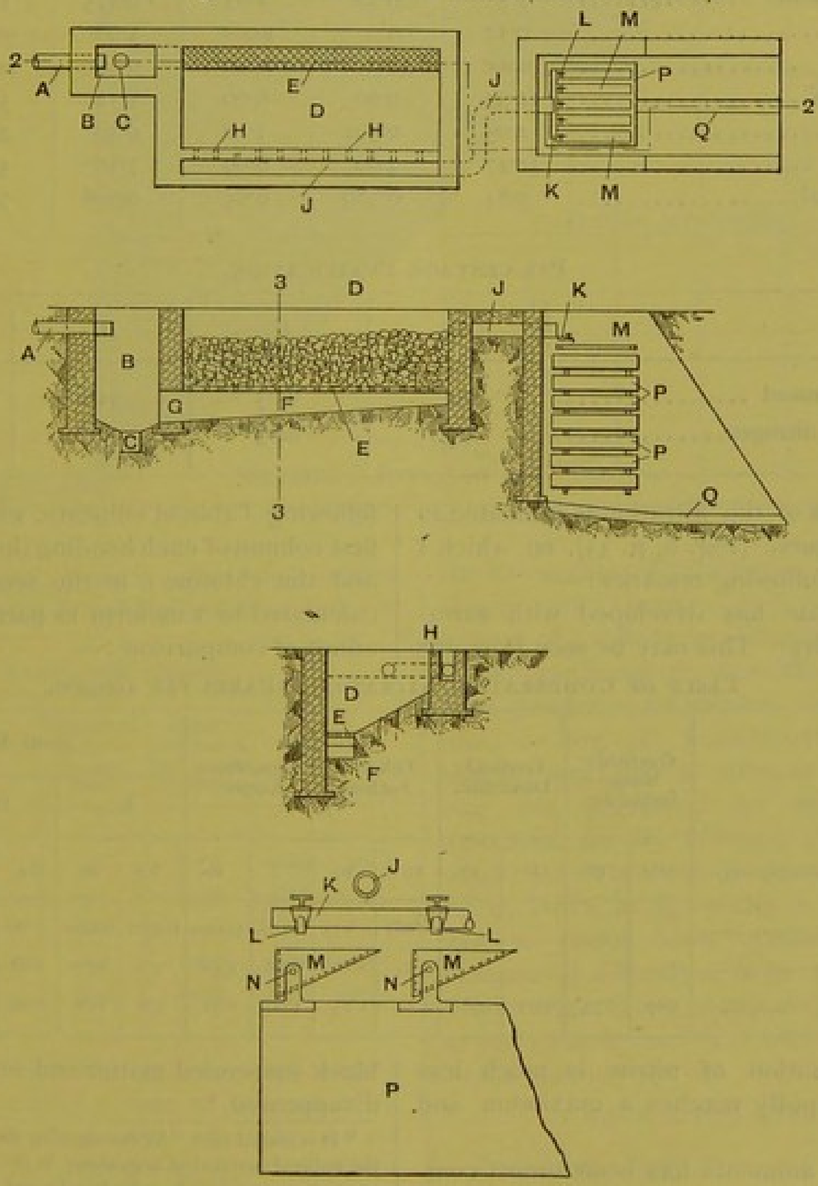
	Substances dealt with.	Characteristic products.
INITIAL. Transient aerobic changes by the oxygen of the water-supply, rapidly passing to:—	Urea, ammonia, and easily decomposable matters.	
FIRST STAGE. Anaerobic liquefaction and preparation by hydrolysis.	Albuminous matters. Cellulose and fibre. Fats.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

It has been already pointed out that in ordinary bacteria beds these reactions are somewhat fortuitously reversed and confused, according to the periods of filling or rest, the fault being caused by mixing all the different bacteria in one or two large filters.

By using a series of smaller, separate areas, and passing the effluent continuously and progressively through them, with ample opportunity for the access of the air where it is required, the organisms gradually choose their own conditions, and allied groups gather together at different levels as coatings on the filtering material. In the later sections the nitrifying organisms are almost alone, and are therefore able to exert their full activity. In this way Mr. Moncrieff has secured a much higher nitrification than has been attained by the other processes.

This he has accomplished by spreading the "tank effluent" by tipping troughs or distributors over the uppermost of a series of "nitrifying trays." (See Fig. 4.) The plant in use at Ashtead for a domestic

FIG. 5.—SEWAGE FILTER TANK (Scott-Moncrieff).



sewage consists of nine perforated trays containing coke, supported vertically over one another at about three inches apart. Each tray has an effective area of one square foot and contains seven inches of coke, broken to one inch diameter. It requires only from eight to ten minutes for the liquid to pass through all the trays. (Fig. 5.) In the early part of last year, after the apparatus had been running continuously for three months, I collected on two occasions samples from the different trays and examined them separately. The rate of flow was approximately measured as follows :—

	Flow observed. Per sq. foot.	Equal to gallons per acre per 24 hours.
Jan. 25, 1898.	1 litre in 15 minutes.	884,600
Feb. 8, 1898.	1,140 c.c. in 12 mins.	1,253,400
Mean ..		1,071,500

The results of analysis are given in the Table :—

PARTS PER 100,000.

	I.		II.		III.	
	0	9	0	9	0	9
Chlorine	9·0	7·5	6·3	6·4	5·5	5·5
Ammonia	11·5	0·25	4·25	0·755	4·0	0·42
Albuminoid ammonia	1·5	0·60	2·93	0·475	1·472	0·107
Nitric nitrogen	0·12	9·0	none	5·98	none	4·34
Nitrous nitrogen	none	slight trace	none	0·06	none	0·034
Total unoxised N....................	12·35	0·60	6·60	1·12	5·35	0·148
Organic N...........................	2·05	0·394	3·10	0·50	2·06	0·113
Total nitrogen	12·47	2·60	6·60	7·16	5·35	4·522
Oxygen consumed....................	9·84	0·589	9·05	0·608	7·52	0·632

PER-CENTAGE PURIFICATION.

	I.	II.	III.	Average.
(1) Oxygen consumed	94	93·3	91·6	93
(2) Oxidation of nitrogen..............	93·7	84·3	96·7	91·6

The progress of the nitration is indicated in the annexed curve (Fig. 6, p. 33), on which I may offer the following remarks :—

1. The nitrate has developed with extraordinary rapidity. This may be seen from the following Table of effluents, which gives in the first column of each heading the original results and the chlorine ; in the second, the results calculated to a uniform 10 parts of chlorine, to admit of comparison :—

TABLE OF COMPARATIVE NITRATION.—PARTS PER 100,000.

	Garfield : Manufacturing.		Garfield : Domestic.		Dibdin : Sutton.		Cameron : Exeter.		Scott-Moncrieff.					
									I.		II.		III.	
Chlorine	22·4	10	11·0	10	12·8	10	7	10	7·5	10	6·4	10	5·5	10
N as Nitrite..........................					·067	·052	trace.	trace.	trace.	trace.	·06	·09	·034	·062
N as Nitrate					1·53	1·20	1·06	1·51	9·0	12·0	5·98	9·35	4·34	7·9
Oxidized N	1·67	0·75	0·95	0·86	2·20	1·25	1·06	1·51	9·0	12·0	6·04	9·44	4·37	7·96

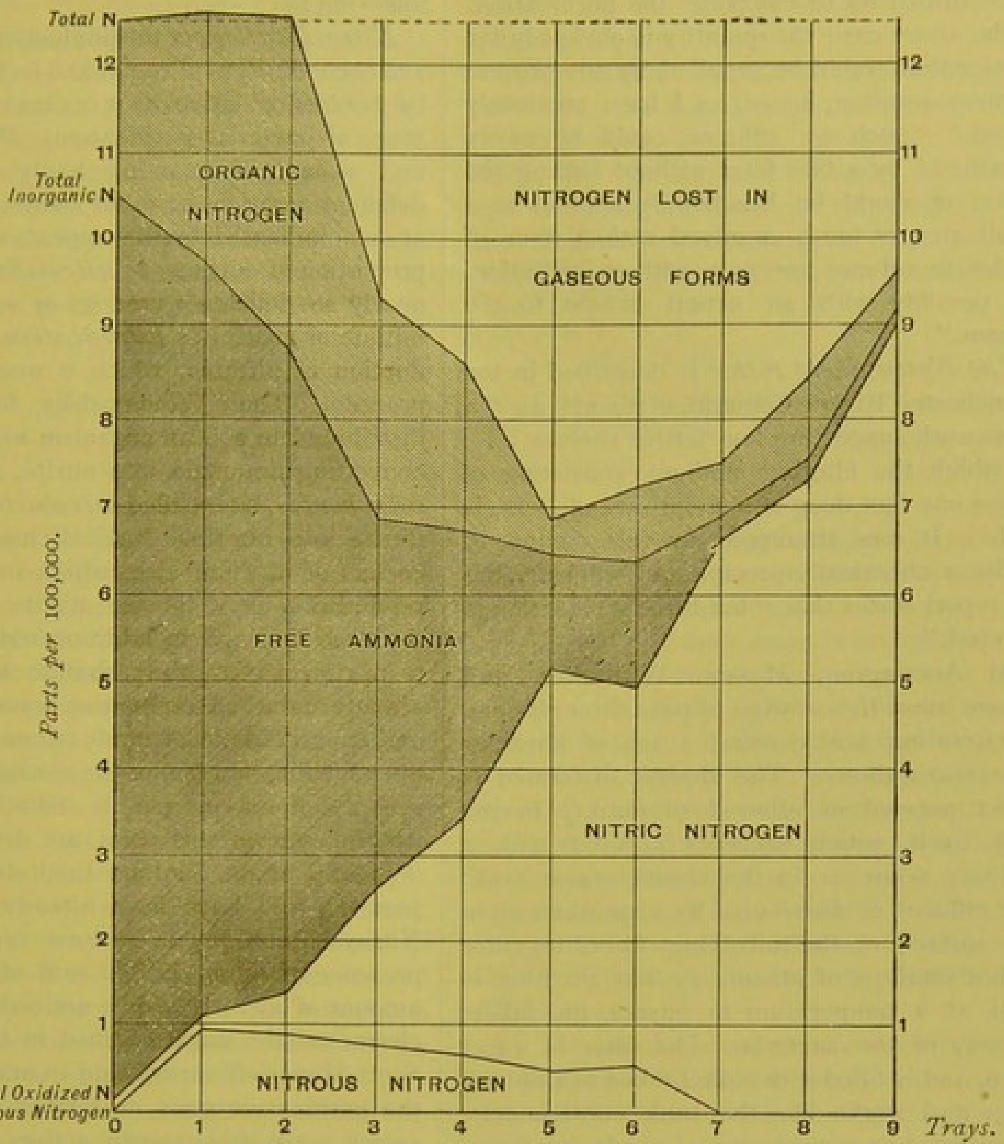
2. The formation of nitrite is much less marked ; it rapidly reaches a maximum and then declines.

3. The free ammonia has been almost completely oxidized ; at the same time it was noticed that the original yellowish colour, black suspended matter and sewage odour had disappeared.*

---

* It is stated that " by transposing the trays so as to upset the natural survival of organisms in the sequence, the whole process was arrested, a high-coloured and inferior effluent being the immediate result, and one or two days were required to re-establish the conditions that had been disturbed."

Fig. 6.—Nitrification in Bacterial Trays (Scott-Moncrieff System).



The following figures give the oxygen relations which I found for the first and last trays :—

Parts per 100,000.

	Dissolved Oxygen. cc. per litre.	Oxygen consumed by organic matter.	Available oxygen.
Jan. 28th—			
Original ……	—	9·54	*minus* 9·57
Last tray……	—	0·39	*plus* 20·1
Feb. 8th—			
Original ……	0	9·05	*minus* 9·05
Last tray……	6·34	0·44	*plus* 12·99

The organic matter has been very greatly reduced for so brief a time of contact. The effluent is now in a state of rapid natural purification by means of its "available oxygen," a term I some time ago proposed for effluents rich in nitrates. We know by the researches of Warington, Munro, Adeney, Gayon and Dupetit, and others, that the oxygen of a nitrate is utilised for the burning up of organic matter, *provided the latter has been properly fermented,* as in this case it has. In my own experiments I have found that the large loss of nitrogen so often noticed was not accounted for by nitrous acid, ammonia, nor by nitrogen gas. Gayon and others have observed the production of nitrous oxide, which being soluble is not evolved and has no doubt been overlooked by many observers. Therefore, to be on the safe side, I have allowed four atoms of "useful oxygen" to every two molecules of nitric acid, according to the equation :—

$$2\,HNO_3 = H_2O + N_2O + 4O.$$

Deducting from this the "oxygen consumed" figure, as representing the organic matters which are fairly easy of destruction, I call the surplus "available oxygen," ready to be drawn on to complete the purification. In the above case the quantity is obviously far greater than would be supplied by any process of mere aeration, hence, as I have previously stated,* "such an effluent could be easily 'finished' by a fine filter without fouling the latter, or could be beneficially applied to a small area of land, or mixed with a river of moderate volume not only without pollution, but possibly with an actual benefit to the stream."

The Noton Shelf Filter is described in the Manchester Rivers Committee report† as "a framework supporting four lattice shelves . . . on which the filtering medium, consisting of layers one foot deep of blue furnace cinders, is laid." It was attempted by this means to nitrify a chemically-precipitated effluent, but the report states that "but little purification is effected."

At Accrington, Messrs. Whittaker and Bryant allow the sewage to pass through open precipitating tanks, using 1 ton of lime per 1,000,000 gallons. The sludge so formed is either pressed or allowed to putrefy in the tank itself, which becomes covered with a leathery scum as in the closed septic tank. The effluent is distributed by a sprinkler on to the surface of the nitrifying filter, together with a small jet of steam, so that the filter is kept at a temperature to ensure the fullest activity of the bacteria. The filter is 9 feet deep, and is filled with coke broken to a 2½ inch ring, and works like the tank continuously, provision being made for a steady stream of air passing through the drains at the bottom up into the centre of the bed.

Major Bennett, the borough engineer of Southampton, has introduced at the Portswood Sewage Works a system including an anaerobic bacterial tank, followed by an aerobic or oxidation bed, which is reported to have been dealing "with a large volume of strong sewage for the past six months with remarkable results." It claims several advantages.

I will now give a brief summary of the changes through which the organic nitrogen of offensive matter passes on its way to the final inorganic products. The formation of transition substances and of ammonia we have already noticed, also the copious production of nitrogen gas, which in part is the direct secretion of certain bacteria, but more largely is the result of interactions, such as the following:—

Nitrosification, or the production of nitrites, and secondarily of nitrogen and its lower oxides, by *partial* oxidation, as it occurs in the second stage of bacterial purification. Wherever we find a final filter acting badly, either from deficient aeration, or other cause, the fault is at once indicated by the appearance of a high proportion of nitrites, as *nitrosification* is not nearly so delicate a process or so difficult to initiate or control as *nitrification*, or the production of nitrates, which it would naturally precede. Thus Winogradsky found widely distributed in soil an organism *nitrosomonas*, converting ammonia into nitrite, and another, *nitromonas*, later called *nitrobacter*, changing nitrite into nitrate. P. F. Richter isolated a coccus of medium size, which in 20 minutes produced a very intense nitrite reaction *in fresh urine*, and in addition reduced nitrate to nitrite, a retrograde change which I have already remarked as common to many bacteria, and characteristic of crude attempts to introduce nitrification before the sewage is properly hydrolysed and prepared. Some of my own experiments on this point are detailed in the "Journal of the Sanitary Institute," vol. xix., part iv., and have been already referred to. Nitrosification proceeds most rapidly in the presence of diffused light and of a moderate amount of air. It will be noticed that it is a characteristic stage reached in the earlier of Scott-Moncrieff's trays, and in many processes the purification goes no farther, when nitrification is not subsequently active.

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

One gramme of nitrogen requires :—

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

So that to nitrify in an effluent, five parts of nitrogen per 100,000 (1 gramme in 20 litres) will demand half its volume of air, or

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* "Journ. San. Inst.," vol. xix., part iv.

† March, 1898.

14.3 times its volume of fully aerated water. This explains the comparative failure and frequent collapse of filter beds in large masses, especially if the fluid is a raw sewage or a merely screened or precipitated effluent without preliminary hydrolytic change, as with every 100,000 gallons of sewage, at least 50,000 gallons of air must be continuously supplied.

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

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

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

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

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

The change is therefore accompanied by a great loss of nitrogen, and a disappearance of odour. It takes place in the resting-full period of filters, and causes disappearance of more nitrogen than carbon.

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

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

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

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

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

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

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

(*d*) Darkness and free admission of air.[†]

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[*] Winogradsky, Centr. Bakt., 1896, 2, ii. 415 and 449.

[*] *Comptes Rendus*, cxiv., 181.

[†] At this point I may incidentally draw attention to a curious fact. In nearly all published analyses, the chloride in the effluent is slightly lower than that in the corresponding sewage. Muntz pointed out that in nitrification, bromides and iodides were oxidised to bromates and iodates. Chili saltpetre (nitrate of soda), which has been produced by natural nitrification, almost invariably contains chlorates and perchlorates, sometimes amounting to 7 per cent. of the former and 5 per cent. of the latter; they are supposed to have been formed by bacteria. Dr. Tidy, some 20 years ago, found a loss of chloride in waters running over aerating wooden shelves, and suggested that it might be due to the formation of chlorates. (*Journ. Soc. Chem. Ind.*, Dec. 1898, p. 1160).

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

Denitrification.—Two organisms were isolated from sewage by Gayon and Dupetit in 1886[*], which, in the presence of organic matter, decomposed nitrates evolving nitrogen and nitrous oxide. They proved that the whole of the N was evolved, and that all the O of the nitrate united with the carbon of the organic matter to form CO_2, part of which united with the base to form acid carbonate.

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

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

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

Adeney, in fact, introduced a process in which he added artificial nitrate of soda at the third stage to accomplish by denitrification the final removal of any organic matter present, but as we have seen that the effluent is naturally nitrified by properly constructed filters, the expense of an artificial supply can be avoided.

This brings us to the question of *what is a satisfactory effluent?* In a paper at the last meeting of the British Association at Bristol,[‡] I discussed the various standards that had been adopted at different times. The popular permanganate test for "oxygen consumed" is open to the objections that:—

1. So many modifications have been introduced in precedure that the figures obtained by different observers are seldom comparable, as instanced in the recent discussion at Manchester.
2. It mainly measures the carbonaceous matters which are not the most noxious.
3. It is incomplete even in measuring these, since many of them are very resistant to permanganate if used, as ordinarily, at low temperatures. For this reason I prefer to work at a higher temperature, namely, that of a water-bath at 80° *centigrade*, giving 2½ hours.
4. The influence of nitrites, which are abundant, as we have seen, in certain stages of purification, of high chlorides, and of iron and manganese salts derived from a chemical treatment, has not been satisfactorily eliminated, even by the adoption of time-limits, such as 3 minutes 15 minutes, 2½ or 4 hours.

Still more delusive is the *albuminoid ammonia*. Its absolute amount has little or no meaning, the main question being the *quality* of the matters yielding it, and the nature of the accompanying substances.

I have noticed that many dilute putrid sewages of offensive character have shown less albuminoid ammonia than the condemnatory limits of existing standards, and conversely, many effluents in a healthy state of self-cleansing have exceeded the arbitrary margin that is sometimes laid down.

Incubation tests, as adopted in the Manchester report, maintain the effluent for five days at 80° Fahr., and determine the oxygen absorbed in three minutes before and afterwards, also noticing any change of odour. The result is still arbitrary, as an effluent is not intended to be stored by itself, but when finished, to be discharged at once into water, which is moving and aerated.

In the above paper I also reviewed the standards of several local authorities, and pointed out that in these conventional limits no account was taken of the respective volumes of the effluent and the stream into which it discharged, nor of the local conditions and subsequent use of the stream for drinking purposes. Standards founded on the number of bacteria are also of little value, although only a low number of organisms of the Coli group should be permissible, with an absence of dangerous pathogenic forms.

In the first lecture I explained a formula for estimating the volume of a given effluent that

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[*] Station Agronomique de Bordeaux.

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

[‡] "San. Record," Sept. 23, 1898.

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

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

might be permitted to pass into any particular stream, founded on the ratios of oxidation.

I have on many previous occasions pointed out that a "calculation of the *ratio* between the different forms of nitrogen furnishes a clearer idea of the history and character of an effluent than a mere consideration of its amounts." Besides the formation of free ammonia in the transition or preparatory stage, and the conversion into nitrite and nitrate at a later period, we have seen that there is a considerable dispersion of organic nitrogen in the form of innocuous gases. I believe I am the first to propose an expression for the measurement of this important phase of the purification, obtaining the data from the

RATIO OF THE CHLORINE TO THE TOTAL NITROGEN.

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

Let Cl and N be the parts of chlorine and nitrogen respectively, the "residual ratio" will be :—

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

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

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

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

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