BACTERIAL TREATMENT OF SEWAGE.

BY

R. EUSTACE TICKELL, M. INST. C. E.,

Chief Resident Engineer, Colombo Drainage Works.

There is probably no engineering question, the solution of which had made greater strides in the last twenty years than that of the disposal of sewage; and this has been due to the rational application of biological researches into nature's own methods of disposing of the waste products from animal and vegetable decay, and the adoption of those methods in a concentrated form to meet the accumulations which have to be dealt with from the population of cities. Those researches have abundantly proved that whether the sewage is spread over the land as manure, turned into streams, or otherwise disposed of, the purification which takes place is mostly due to the action of numerous varieties of microorganisms, which are ordinarily present in all soil and water, ready to multiply into enormous numbers with almost incredible rapidity as soon as they are presented with suitable conditions, and to seize upon the organic matter in the sewage and reconvert it into its original inorganic components.

The chemical changes produced by the bacteria have been studied. The microbes have been cultivated, photographed, fed, starved, boiled, frozen, poisoned, and subjected to all the various indignities meted out to objects of scientific examination, and the Civil Engineer then set about to design habitations for them where they might live in the greatest possible ease and comfort at the expense of the ratepayer.

The varieties of bacteria are so numerous, and their requirements differ so widely, that little pro-
gress was made with the subject until one broad distinction was made between those that flourish in the absence of oxygen or Anaerobic, and those which flourish in the presence of oxygen or Aerobic. The anaerobic deal with the solids in suspension and represent the process of liquefaction. The aerobic deal with the solids in solution and convert them into nitrates and nitrites; they represent the process of oxidation; to them is largely due the purification effected by filtration, and their presence in the rivers is the explanation of the remarkable manner, in which sewage solution has been observed to disappear from shallow running streams within a few miles of the source of contamination. Oxygen, which is the breath of life to most organisms, was found to be actually poisonous to anaerobic bacteria, so the importance of dividing the treatment of sewage into two separate stages became evident.

The aerobic microbes set up a putrefactive ferment which decomposes the urea, albuminous matters, cellulose, and the fatty compounds. The process is carried out with many successive and complex chemical transformations, most of which are in the early stages quite inoffensive. Very little real purification is effected by them, but the sewage is rendered capable of being more rapidly dealt with by the subsequent action of our best friends the aerobic bacteria. The action of the anaerobic can be readily observed wherever sewage is stagnating in ditches or ponds; without their presence the ordinary cesspool would soon become choked with solids; whereas cases have been known where such receptacles have been in use without being cleaned out for years. The proper habitation for the anaerobic microbe is in the sewer and the septic tank, where the sewage can be retained under official regulations for the proper period sufficient for hydrolysis and for no longer. Pasteur and others knew all about the anaerobic bacteria many years before anyone attempted to utilise them in the treatment of sewage. Such an idea was totally at variance with established practise. Everyone was endeavouring at that time to extract the greatest possible amount of organic solids from the sewage by means of precipitation, the more sludge they obtained the better they were pleased, and here was a wretched microbe which was going to throw it all into solution.
In 1891 Scott Moncrieff constructed what he called a cultivation tank for dealing with the sewage from his country house. He recognised in the liquefying bacteria a means of reducing the sludge which would cost absolutely nothing, and he collected evidence which went to show that further purification was attainable by bacterial processes alone; and subsequent investigations surpassed the most sanguine expectations of the early explorers in this field.

The value of the work done by the anaerobic bacteria may be judged by the fact that at Exeter, where one of the first septic tanks was put into operation, it was found that out of 2.5 grains of solid matter per gallon of sewage, 20 grains were liquefied in the tank; which, if precipitated, would have represented about 300 tons of sludge per annum per thousand persons.

So far merely the liquefaction of the organic matter has been touched upon, the final purification takes place in the subsequent process of oxidation which is effected by the aerobic bacteria.

Experiment after experiment was carried out in America and in England, and success was attained in proportion as the conditions of existence of the aerobic bacteria became better understood. Filtration was tried through beds of coke, gravel, and various kinds of ballast. The bacteria appeared soon enough, but the difficulty was to keep them supplied with sufficient oxygen. Just as the land when overdosed with sewage became "sewage sick," so it was found that the beds became gradually choked, but that they recovered in a remarkable degree after a more or less prolonged period of rest.

It was in view of these considerations that Mr. Dibdin arrived at the construction of his contact-beds. He filled a tank with gravel and admitted the sewage slowly into it, allowed it to stand full for a few hours and then slowly emptied it. The surface of every particle of the gravel soon swarmed with the necessary bacteria in a high state of activity, and every time the bed was emptied a fresh supply of air was drawn into the interstices of the gravel which kept the bacteria going while the bed remained full. The bed was allowed to remain empty for a few hours for thorough aeration before being again filled with sewage. The purity of the effluent was simply astonishing, it was bright and
clear, absolutely devoid of smell, fish lived in it, and it showed no signs of putrefaction when kept in open or in stoppered bottles for any length of time. It had in fact gone through exactly the same process within the small compass of the contact-bed that would have been followed, if the sewage had been irrigated over a large area of land, and been allowed to filter through the soil. The only difference being that in the artificial bed the bacteria were better supplied with oxygen, nourished in greater numbers, and were consequently able in a shorter time to accomplish the same work in a smaller area.

The main principles of action having been so far established, it remained for the Engineer to improve the conditions so as to effect the greatest possible purification in the smallest possible area at the least possible cost.

The disadvantages of the contact-bed were that the action was intermittent. The unfortunate microbes were alternately surfeited and starved, and anaerobic action was proceeding during the time the bed remained full. The efficacy of these beds consequently deteriorated in the course of time and their capacity became diminished by deposits and by fungoid growths. An improvement on this arrangement was effected by the introduction of what was called a "continuous filter," in which the sewage is sprinkled over the surface of the bed and trickles through the gravel, forming a thin film of liquid flowing over the surface of each stone. The flow is regulated so that the films of liquid do not coalesce by capillary attraction and the interstices between the stones are maintained full of air, a fresh supply of which is continually being drawn in by the flow of the liquid. By this means the maximum superficial area is provided for the exposure of the sewage in a limited space, and each drop obtains the greatest possible reaction. It is a misnomer to call the installation a continuous filter. The action is in no way similar to the straining operation usually understood by the term filtration, but it is in reality an aerobic bed dependent upon the bacteria it contains; neither is it strictly speaking continuous, for drop follows drop with a momentary interval between, and, if the volume of flow is increased so as to create a continuous run, a fungoid growth will appear, and the bed will require a period of rest.
Such aerobic beds have now been in operation for several years with most excellent results. When not overworked they are absolutely inoffensive, the gravel remains clean throughout, and the effluent uniformly free from any symptoms of putrefaction. With reference to this point, the Royal Commission on Sewage Disposal reported in July, 1901, that many valuable experiments on artificial treatment had been made by a number of local authorities, and in particular the corporation of Leeds and Manchester had subjected certain processes to sustained observations and obtained much reliable information; and they gave one of their conclusions as follows:—

"After carefully considering the whole of the evidence, together with the results of our own work, we are satisfied that it is practicable to produce by artificial processes alone either from sewage or from certain mixtures of sewage and trade refuse such, for example, as are met with at Leeds and Manchester, effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance."

It must however by no means be assumed that we have come to the end of advances and discoveries in the purification of sewage. Serious complaints have been advanced against the anaerobic bacteria. Some people are never satisfied, and in spite of the thousands of tons of municipal sludge which has been consumed annually by their action, they have been accused of not doing enough work, of encouraging fungoid growths, and generally making themselves objectionable in a way that no decent aerobic microbes ever think of behaving; and there is no doubt that when they are overflowed they can create an intolerable nuisance. Mr. Diiladin says he has no use for them, and would like to see their house allowance in the septic tank struck off the estimates; but it seems to me that there can be very little doubt that they are doing a good deal of work for him during all the time his contact-beds are standing full. He has recently contributed another book on the subject, entitled: "Recent improvements in methods for the biological treatment of sewage," in which he advocates the use of slate filling in the contact-bed. The idea appears to
be that thin slabs will give greater surface for sewage contact in comparison with the bulk; whereas, in the material hitherto adopted, the interior of every stone is uselessly occupying water space. Experiments at Doverses and High Wycombe gave better percentages of purification from slate filling, than from broken stone or coke, and the water capacity of the slate bed was 82% as against 30 to 40% in other beds. A deposit of humus gradually formed on the slates, which proved to be harmless, that is to say non-putrefactive, and it could be flushed out with a hose when the accumulation became excessive. The slates were laid in horizontal layers, supported on distance pieces, 4 inches between layers. This spacing was found by experiment to give the best results; which is rather remarkable, as it is at variance with the hypothesis that the improvement was due to increased surface area for sewage contact, in fact the surface area of such a bed I calculate to be less than one-third of that of 2" broken stone.

It has always been found that the water capacity of contact-beds decreases with use. They can be partially restored by periods of rest, but after some years it is generally found necessary to have the material taken out and washed. The sludge which forms in a septic tank must also be developed in a contact-bed during the time it is standing full. It stands to reason that it must be unscientific to encourage anaerobic conditions in any kind of bed which is intended to be used for oxidising the sewage. Dr. Riddle remarks on this: "Two different things were attempted with contact-beds. The first was anaerobic decomposition or hydrolysis, best conducted in a septic tank; the second was oxidation pure and simple, which was best conducted in continuous filters. Mr. Dibdin had tried to combine the two processes in one bed, that had resulted in neither of them being done properly."

The advocates of the septic tank argue: here is a tank with 100% water capacity; containing no material which will require to be taken out and cleaned. It is intended for the exclusive use of the anaerobic bacteria, and separate accommodation of an entirely different design should be provided for aerobic action.

Notwithstanding the truth of this reasoning it may yet be found that the contact principle possesses
a merit of its own which has not been sufficiently
taken into account.

When you consider the heterogeneous components of sewage, and come to think that we have
to deal with millions of colonies of bacteria, which
differ in kind and require different foods, and
different surroundings, the simple division into
aerobic and anaerobic bacteria must be regarded as
a very arbitrary classification: like "Jack Spratt
could eat no fat" and might presumably be
employed in the reduction of the cellulose which
Mrs. Spratt wouldn't look at.

There must be vast communities of unfortunate
microbes whose energies have not been fully
utilized because they have failed to find some
necessary condition of existence in either the septic
tank or the aerobic bed as hitherto constructed. It
is therefore probable that some variation in the
present methods of treatment will be followed by
new discoveries and fresh advances in the future.

A considerable proportion of the solid matter in
sewage (50 or 60%) is in a colloidal state. That is
in pseudo solution, of a gluey nature, like gelatine.
The fluid colloid becomes pectous or curdled and
insoluble by contact with other substances and the
invisible solids which it contains are capable of subse-
quent transformation and precipitation.

An installation has been recently set to work at
Hampton-on-Thames, with a septic tank of novel
design especially intended to collect and deal with
such matters, and a paper by Colonel Jones and Dr.
Travis "On the elimination of suspended solids and
colloidal matters from sewage," describing these
works, was read before the Institution of Civil
Engineers on 8th January, 1906.

The sewage of Hampton is collected on the
separate system, and no storm water has therefore to
be dealt with; another peculiarity is that it has to
pass through a great length of rising main which
contains nearly a day's flow, so that when the treat-
ment works were designed in 1898, it was thought
that a septic tank could be dispensed with, and the
crude sewage was turned direct on to a series of triple
contact-beds. The capacity of the beds proved to be
too small and the filling material too fine (\(\frac{3}{4}\)" to \(\frac{1}{4}\)"
and less). The beds became greatly overloaded, with
the inevitable result that they silted up and large
areas of the interior were found to be almost solid.
The life of the beds was prolonged for a time by careful screening; until it was seen that some preliminary tank treatment was absolutely essential. Experiments were commenced in March, 1904, which resulted in the construction of what the authors termed a hydrolytic tank and chambers. The hydrolytic tank is a small septic tank of somewhat complicated construction, with a capacity of about 6 hours' flow. It is divided longitudinally into three compartments, two outer and upper sedimentation chambers, and one middle and lower liquefying chamber, the partition walls are formed of thin slabs about 2 feet apart at the top and sloping outwards and downwards at an angle of about 45°. The subsiding particles in the sedimentation chambers settle upon the upper sides of the slabs and slide down through openings into the liquefying chamber below, whilst the gases from the liquefying chamber rise up in bubbles which follow the under sides of the slabs and escape through a central passage without disturbing the liquid in the sedimentation chambers. At the outlet end, the sewage passes over weirs, which are so arranged that the rate of flow in the sedimentation chambers is seven times that in the liquefying chamber, and the volumes are such that the sewage is 5 hours in the sedimentation chambers and 15 hours in the liquefying chamber. The tank is ventilated by a fan driven by a steam engine. About 3,000 gallons of sludge are drawn off from the liquefying chamber every fortnight.

The hydrolytic chambers consist of a series of four upward flow filters filled with broken flints 3° to 6° diameter, with a water capacity equal to about 3 hours' flow of the sewage. Arched conduits are provided at the bottom for the removal of sludge.

Seven eighths of the sewage is therefore 8 hours, and one eighth is 18 hours under hydrolytic treatment. The quantity of sludge removed was stated to be 10 tons per million gallons or 47.6% of the quantity received; and the effluent showed a reduction of 63.8% in the albuminoid nitrogen, which is 10 or 12% more than is usually effected in a septic tank. After this treatment the old contact beds were able to effected a further reduction of 29.3%, making 93.1% in all; the albuminoid nitrogen in the final effluent was then reduced to .08 parts per 100,000 which was within the required standard of purity.

In describing these works before the Institution, the authors stated that one of the objects of their
paper was to show that bacteria played only a subsidiary part in the purification of sewage. But this somewhat startling opinion was controverted by every one of the leading authorities who took part in the subsequent discussion, and the value of their contribution has perhaps been unduly discounted in consequence.

The most interesting feature of the installation however is an experimental model tank with glass sides so that the process of purification could be observed in progress.

The model tank, which is about 12 feet long by 2 feet wide, differs from the main installation in one very important particular. The idea of the sloping slabs had been further developed. Instead of the broken flint filling of the hydrolytic chambers, the second division of the model is fitted throughout with a number of slabs set transversely, about 2" apart, with a steep slope towards the outlet, reaching from near the water surface to about two thirds of its depth.

The colloidal matter which had escaped from the first division of the tank formed a slimy and sticky deposit which adhered to the upper surfaces of the slabs, where it could be seen to undergo a gradual change, until it became a loose and granular sludge which became detached and slid down the slabs to the bottom of the tank. The rising gas bubbles followed the undersides of the slabs and so did not interfere with the formation or final settlement of the deposit.

The model dealt with 1,500 gallons of crude sewage a day, and, as its capacity is about 30 cft. after deducting the space occupied by sludge, the liquid remained in the tank for only 3 hours. In this short time the suspended matter was reduced from 35 parts to 1 part per 100,000 and the albuminoid nitrogen was reduced by 58.5%.

Now whether the transformation was effected by purely mechanical means, as Colonel Jones would apparently have us believe, or by the action of bacteria as is generally supposed, all the authorities are agreed upon the importance of surface attraction and the necessity for providing ample surface areas for the collection and resolution of the colloidal matter. It is therefore apparent that a large proportion of such matter must escape from any ordinary septic tank and be retained upon the material of the
aerobic beds, which will tend to choke them up and reduce their efficiency by the amount which the aerobic bacteria are incapable of dealing with. It is probable that the deposit which Mr. Dibdin found on his slates was largely due to matter in a colloidal state; and a somewhat similar deposit has been found in the effluent from sprinkling filters. The sprinkling filter is to a great extent self cleansing, and the deposit has not usually caused any very serious difficulty.

Now, although there is very little reason to doubt that the colloidal matter can be dealt with under aerobic conditions in a continuous filter, it is quite possible that it may be more effectively treated under anaerobic conditions in the still waters of the septic tank.

It may be that there is a large class of microbes which perish for lack of seating accommodation in the septic tank, and cannot live in the atmosphere of the sprinkling filter. Such a population would find only an intermittent livelihood in Mr. Dibdin's slate beds at Devizes, but they would flourish in their millions on the slabs of the model tank at Hampstead. Here then is a new condition, which would appear to present a more promising application of the contact principle than any which has been hitherto put forward, and for this reason, that the slabs appear to be self cleansing. No kind of filling, such as broken stone, which may require cleaning, has yet been found satisfactory for continuous flow, but by supplying the required surface areas in the form of thin slabs from which the deposit can drop off, the septic tank, or preferably some portion of its length, can be converted into what might be described as a continuous flow contact-bed, and we might have an ideal installation with an uninterrupted forward flow through septic tank, contact-bed, and sprinkling filter. We could then probably afford to ignore the requirements of any fastidious microbes which were unable to accommodate themselves somewhere under such a variety of conditions.

It remains to be seen whether these experiments will stand the test of time and how far the experience gained with the sewage of Hampton, which as already pointed out is of an exceptional character, can be applied under more ordinary circumstances, where sewage is delivered at the treatment works within two or three hours of its collection. It can hardly be
doubted that greater capacity in the septic tank will be found necessary, and it remains to be seen whether any considerable increase can be made in the rate of flow through aerobic beds. It would therefore be the height of imprudence to attempt any reduction in the capacities of tanks and filters in the design of treatment works at the present time. But, if the theory should prove to be correct, it is satisfactory to think that works which are constructed on the lines of established practice may, by the simple introduction of the above described thin slab contact surfaces into the septic tank, be made capable of dealing with an increased flow of possibly 10 or 12%, thereby increasing their capability to meet the growth of population for several years beyond the estimated time for which the works had been designed.

Mr. Rothwell asked if Mr. Bellamy would explain the object of the rotary distributors, and also if he could give them the name of the best form in use at the present time.

Mr. Ward said he would like to know whether coral had been tried as a filtering media; and, if so, how it acted.

Mr. Fruhling asked if ordinary stoneware pipes, placed vertically in the aerobic, were not sufficient for aeration, and also whether the herring bone system of distribution was not effective.

Mr. Bellamy, who read the Paper—the author being absent through illness—in reply to Mr. Rothwell, stated that the object of rotary distributors was uniformity of distribution, so that each portion of the area may receive the same amount of liquid. The delivery of the liquid ought to be in the form of raindrops. There were so many different varieties on the market, that it was a difficult matter to say which was really the best type. With regard to Mr. Ward’s question, he had heard of coral mentioned as a media many years ago whilst in Australia, but he could not give any particulars as to whether it had been tried.

With reference to stoneware pipes being placed vertically in aerobic beds, he failed to see what object they served, unless used in conjunction with a tiled or perforated floor. The herring bone system of distribution merely consisted of half round tiles laid on the top of a bed in herring bone fashion. Experience proved long ago that the distribution by this means was too uneven.
Mr. Atkins. Mr. M. R. Atkins said, Mr. Bellamy had referred to the mechanical driving of sewage distributors and the speaker might mention that such assistance was certainly required when the distributors were placed on exposed sites. The tendency was for the distributors to come to a standstill during heavy gusts of wind with the arms in the "broadside and end on" position.

At Derby, where the first installation consisted of 18 Adam's distributors of 100 ft. diameter, this same difficulty was experienced during high winds with the minimum head of water which was about 5 inches.

After much experimenting with wind-vanes of various kinds, including large and small flaps, fixed cones, cups on the anemometer principle, &c., an arrangement of small flaps pivoted vertically and fixed in tiers in an upright frame at the end of each arm was found to overcome the difficulty, viz: the tendency of the distributor to stop at the critical points of its revolution.

Mr. Bellamy. Mr. H. E. Bellamy said, he was sure that all the members present would regret the unfortunate absence of Mr. Tickell, and he was certain that the value of the transactions of the Association would be considerably enhanced by having such a paper presented to them.

Regarding Mr. Dibdin's idea of using slate filling instead of broken stone or coke, he quite agreed with Mr. Tickell that to make any reduction in the capacity of tanks and filters in the design of treatment works at the present time, through the results of experiments carried out at Devizes and High Wycombe, would be the height of imprudence.

The question of sewage disposal had now assumed a definite position in engineering, with the result that works pertaining to sewage disposal were now being designed on lines that would prove to be more permanent than anything previously constructed.

With regard to the arresting and disposing of the solids contained in sewage, he looked upon this process as most important, and any scheme wherein sludge disposal took a second place was wrong.

Regarding aerobic beds, there is no doubt that a percolation bed is the best form of bacteria bed. The site upon which aerobic beds are proposed to be constructed is most important, and should be selected to admit of the septic tank liquor by
gravitation. The floor should be of the best cement concrete, and upon it should be laid a false floor consisting of specially made tiles. If tiles are not used, the solids are apt to choke the bottom of the bed, thus preventing the effective serving of the bottom of the bed. In England, these tiles cost about £3 per super yard to lay. The period usually taken for the effluent to percolate through a bed takes about three minutes. When a bed has been in continuous working order for about six months, it often shows signs of water logging. This is usually remedied by loosening the surface layer. The medium for a percolation bed should be of good hard rock or other hard substance that will not resolve or become friable by the action of water or atmospheric changes. Where ashes have been used, in many cases, this material requires taking out every three to five years to be washed and replaced. Personally he favoured a 1½" medium. Very small medium does not take so much sewage, it costs more, and retains surface suspended matter.

The question of distribution of sewage over beds was a most important point. For very large beds, where the acreage is not less than 1 acre, he was of the opinion that fixed spray jets requiring a head of 4 to 6 feet is the best system of distribution at present designed. Rotary distributors are seldom used for beds larger than 120 feet in diameter. Mechanically propelled distributors have been tried, with much success, and it was his (Mr. Bellamy's) opinion that they should always be provided where distributors are exposed to much winds. The holes in the arms of the distributors should be of fairly large diameter.

The question of the purification of storm water is still in an unsatisfactory position, and, up to the present time, no satisfactory scheme has yet been devised. It still remains an interesting subject which Engineers might well devote special attention.

Mr. Bellamy also mentioned that, in the absence of Mr. Tickell, he would be pleased to conduct the members of the Association round the Drainage Treatment Works, &c., the following morning.

The following description of these has been compiled by the Author for the information of the Members.