Nitrification of Sewage.

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My special object in this paper is to direct attention to certain observations I have recently made bearing upon depth of filters and grade of particles as affecting both the quality of the work done and the capital outlay involved.

To effect the necessary changes it is essential that the sewage in a fine film shall be brought into intimate contact with the nitrifying organisms in the presence of an adequate supply of oxygen. It follows, therefore, that the larger the number of organisms employed, so long as they are maintained in a healthy active condition, the greater the amount and the better the quality of the work done. How then should a filter bed be constructed, so that, within a given cubic space, it shall afford the largest possible surface for bacterial growth under healthy conditions? Clearly, I suggest, by reducing the particles composing the filter to the smallest size which is found to be compatible with free aeration.

Compare, from the point of view of effective working area, a filter formed of 2-inch cubes—a grade in common use at present—with one formed of $\frac{1}{8}$-inch cubes, and it will be found that, bulk for bulk, the area in the latter case is 16 times greater than in the former, but taking into account the relatively larger space occupied by the smaller particles, the actual gain is as 1 to 14·7.

The question is, then, to what extent in actual practice is it possible to reduce the size of the filter particles? Some four years ago I had an opportunity of conducting an experiment on a large and practical scale at Hanley with a plant which complied with all the conditions which previous experience had shown me to be essential, including, for the first time I believe, perfect and uniform distribution of the sewage on to the filter by means of a power-driven apparatus.

Shortly, this plant, which dealt with 500,000 gallons per day (1,000,000 gallons per acre), consisted of:—

1. A detritus tank and strainer of the usual type.

2. Three subsidence tanks having a total capacity equal to one-eighth the daily dry weather flow.

3. An open septic tank with a capacity of seven-eighths the daily flow

(giving, with the subsidence tanks, a capacity for quiescence equal to a day's flow).

4. Two quarter-acre "percolating" filters 4 feet 9 inches deep, the one circular and the other rectangular, and each having a different type of power-driven distributor. I may here mention that I have long since discarded the "contact" method of working bacteria beds in favour of what is termed "percolating" filtration.

The filtering medium in this case consisted of broken "saggars," the discarded hard-burned clay vessels in which china is packed for firing, and the filters were constructed in four separate sections, each having different graded material. This material ranged (in separate sections) from $1\frac{1}{2}$ inch to $\frac{1}{8}$ inch. I have elsewhere given a full description of the working of this plant during a period of about eighteen months, and the results proved that such filters, working at the rate of 200 gallons per square yard per 24 hours (1,000,000 gallons per acre) continuously, produce a high-class effluent, the best results being obtained from the section of the filter composed of the finest grade particles ($\frac{1}{8}$ inch).

So much for the preliminary work which led up to the present investigations, the results of which seem to me to be of scientific interest and of practical importance.

It would seem to be established that the nitrification of hydrolysed sewage takes place in stages, the nitrous change being effected by one set of organisms as a preliminary to the nitric change brought about by another set, and the theory is that the two sets of organisms are located in different layers of the filter. With the view of verifying this, and, at the same time, ascertaining the degree of purification effected at different depths, I determined to tap the filter which had been used for the purpose of the experiment already referred to, in such a manner that samples might be collected at different levels, and I selected the finest grade section for this purpose ($\frac{1}{8}$-inch particles). Accordingly, four longitudinal shallow trays, with perforated covers, were placed in the body of the filter, the first at 1 foot from the surface, the second and third at 1-foot intervals downwards, and the lowest 18 inches below the third one, pipes being carried from the various collecting trays through the wall of the filter, to allow of the collection of the respective samples. In order that the results from the lower depths might not be affected by the presence of the trays above, the trays were placed obliquely from above downwards, so that no tray had another in the vertical line above it. As the filter at this time had been constantly at work for two and a-half years, in replacing the filtering material which had been disturbed in order to introduce the trays care was taken to ensure as far as possible that each portion

was placed in the position it had previously occupied in the depth of the filter, and seven days were allowed to elapse for recovery before collecting the first samples.

As regards analytical methods, the free ammonia was determined in the usual way by distillation and Nesslerising, and the albuminoid ammonia by Wanklyn's process, the quantities taken respectively being—sewage, detritus tank, and septic tank, 50 c.c., filter effluents, 500 c.c., the former being made up to 500 c.c. by ammonia-free water. The oxygen absorbed was determined by Tidy's process, the nitrous nitrogen by Griess' method, and the nitric nitrogen by Sprengel's method.

In order to discount possible subsequent changes from the lower to the higher oxide, and *vice versâ*, the tests for nitrous and nitric nitrogen were made at the works immediately on the collection of the samples, and again in the laboratory the following day, when the complete analyses were made.

The following figures represent the mean results of a series of analyses, the individual figures of which are given in the detailed tables attached. The samples were collected at intervals extending over a period of about six months, the filters being steadily worked at the previous rate, namely, 200 gallons per superficial yard per 24 hours, and the delivery being uniform and continuous day and night.

In the first place, before commenting generally on the conclusions which may be drawn from the results as a whole, I propose to refer shortly to each analytical record separately :—

1. With regard to the suspended solids it will be noticed that a reduction of 73 per cent. is effected in the detritus tanks, and that a further reduction of 15 per cent. takes place in the septic tank, making a total reduction of 88 per cent., and resulting in an effluent being passed on to the filter containing 7·6 parts per 100,000, exactly one-half of which is mineral matter. This suspended matter, it will be seen, is practically all retained in the top layer of the filter, where the organic portion is liquefied, in all probability, by aerobic organisms. The mineral matter, however, must remain in the filter, and in time, no doubt, it will be found necessary to remove the filtering medium to a depth of a few inches for the purpose of washing it, but so far, after over three years' constant working, no such necessity has arisen. As a matter of fact, if the total mineral suspended solids passing on to the filter during the three years were deposited in a uniform layer over the whole surface, the depth of the coating would be less than $1\frac{1}{4}$ inch.

2. The reduction of the free ammonia at a depth of 1 foot is remarkable, especially considering the fact that the change has been effected in about

Sample.	No. of records.	Total solids.	Solids in suspension.	Solids in suspension, organic.	Solids in suspension, mineral.	Chlorine.	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed in 4 hours at 80° F.	Oxygen absorbed in 3 mins. before incubation at 80° F.	Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	Nitric nitrogen on day of collection.	Nitric nitrogen, day after collection.	Nitrous nitrogen on day of collection.	Nitrous nitrogen, day after collection.	Depth of column necessary to obscure test lines.
																inches.
Sewage	18	170·9	63·5	28·5	34·9	11·0	2·154	0·972	5·019	1·862	2·176	0·02	0·10	0·029	0·029	0·5
Detritus tank ...	13	118·1	17·0	6·8	10·1	10·0	1·643	0·486	2·726	0·975	1·095	0·02	0·09	0·014	0·022	1·6
Septic tank	16	107·8	7·6	3·8	3·8	9·9	1·716	0·340	2·184	0·836	1·571	Nil	0·09	Nil	Nil	1·5
Filter, 1 ft......	16	101·5	0·25	0·16	0·08	9·4	0·036	0·052	0·328	0·093	0·067	1·64	2·07	0·003	0·003	Over 24
" 2 "	16	101·1	0·09	0·005	0·003	9·5	0·020	0·037	0·286	0·077	0·060	1·82	1·99	0·011	0·007	"
" 3 "	16	101·8	0·14	0·06	0·08	9·4	0·009	0·031	0·244	0·060	0·052	1·75	1·85	0·005	0·008	"
" 4·5 "	16	103·5	—	—	—	9·5	0·043	0·027	0·259	0·070	0·039	1·70	1·99	0·005	0·002	"

12 minutes—the time occupied by the sewage in passing downward through the first foot of filter. In my experience it is not unusual to find the free ammonia figure reduced almost to an equal extent in effluents from fine-grade filters, but, hitherto, I had no conception that the change was brought about by so shallow a depth of filter.

I may here mention that the rate of travel downwards of the sewage through the filter was found, as the result of several observations, to vary in accordance with the depth as follows:—

From surface to 1 ft.	12	mins.
„ 1 ft. „ 2 „	12	„
„ 2 „ „ 3 „	6	„
„ 3 „ „ 4 ft. 6 in.	5	„
Total	35	„

This is a slow rate of travel compared with the rate in the case of large particle filters, which, in my experience, in some cases allow the sewage to pass through the entire depth of from 4 to 5 feet in about four minutes.

The rate of travel was ascertained by a series of observations as follows:—The delivery on the filter was stopped until the discharge pipes from the respective trays showed unmistakable signs of diminished flow, when it was started again, the period which elapsed before the discharge from the pipes was restored being taken as the time occupied in the passage downward of the sewage to the different depths.

The free ammonia figure presents one other interesting feature. It will be noticed that the progressive reduction which takes place during the passage downwards through the first 3 feet is suddenly interrupted, a considerable increase in the amount being recorded at a depth of 4 feet 6 inches. Accidental error in analysis does not explain this, for it will be seen on referring to the detailed tables that this increase is invariably recorded, and, as a matter of fact, I verified the accuracy of the results by a second analysis in the case of the first few samples until it became quite obvious that no such explanation of the occurrence was feasible. This phenomenon will be referred to later in dealing with the general arguments and conclusions.

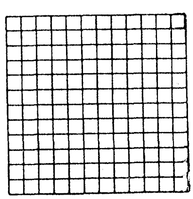
3. As regards the albuminoid ammonia figure, it will be seen that a highly satisfactory reduction is effected by filtration through 1 foot only. In fact, this figure and the oxygen absorbed and nitric nitrogen figures considered together indicate a very high degree of purification, which precludes the possibility of subsequent putrefactive change.

4. It will be seen that the reduction in the oxygen absorbed is, stage by

stage, proportionate to the albuminoid ammonia reduction, and the rapidity of the change in this case also is equally marked.

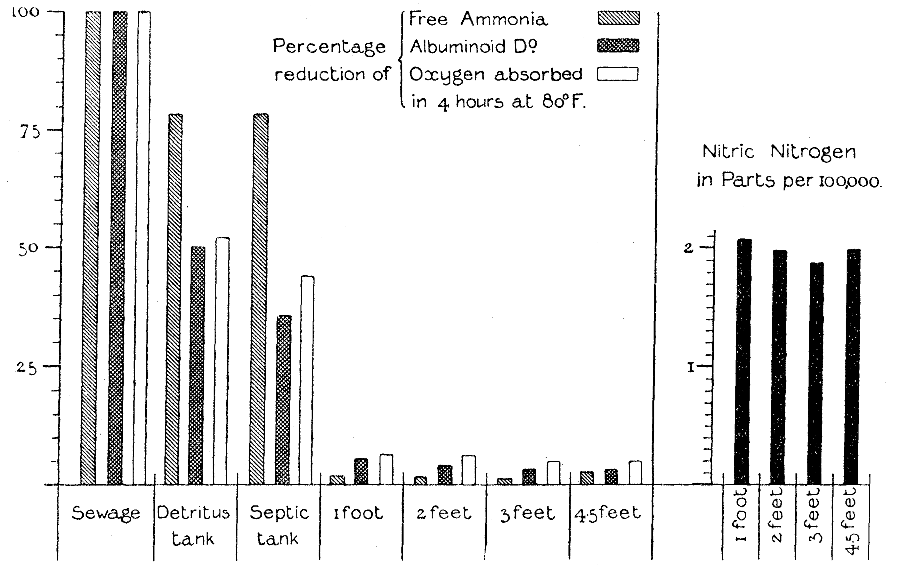
5. With reference to the oxidised nitrogen the figures are very startling, for not only are they indicative of extremely healthy and active biological conditions, but, considered in relation to the other figures, they also demonstrate conclusively, in the case of the sewage in question at any rate, that the work of purification is practically completed within a few inches of the surface of the filter. Within 12 minutes a foul and offensive liquid is rendered not only clear and non-odorous, but also absolutely stable as regards putrescible qualities, as is proved by the oxygen absorbed figures before and after incubation. I must say that this result surprised me very much. Theoretically, as I have said, one expected to find that the process was a more gradual and progressive one, nitrites being formed chiefly in the superficial layers of the filter and nitrates in the deeper layers, but this did not prove to be the case. At the same time I do not suggest that the change is not gradational, but rather that the two sets of organisms are at work side by side, and in this case the absence of more than a trace of nitrous acid in the 1-foot effluent, although the tests were applied at the moment of collection, may be accounted for by the preliminary stage of the oxidation process being an extremely evanescent one owing to the highly efficient working conditions.

6. The column headed " depth of column necessary to obscure test lines " requires explanation. It is a standard opacity test which I adopted some years ago for Staffordshire, and which has since been adopted by some other river authorities. The lines referred to are engraved on a white porcelain disc, which is attached by means of a socket and rubber washer to a 2-foot glass tube, graduated in half-inches. The exact mesh and depth of lines are as shown in the drawing, and in fixing the scale as regards mesh and length of tube, in the first instance, I was guided by my experience at the time as to the opacity of well-clarified effluents. I have since found, however, that the clarification effected by fine-grade filters and efficient distribution is so perfect that the lines are not usually obscured by a depth of 24 inches, and this was the case in the present instance. It will be noticed that while the mean depths of fluid necessary to obscure the lines in the case of the crude sewage and the detritus and septic tank effluents were 0·5, 1·6, and 1·5 inches respectively, the filter effluents, even those from the 1-foot tray, were so highly clarified that the full 24-inch column did not suffice to obscure the lines. It is true that the opacity test in itself is not a reliable index of purity;



at the same time, such a record, considered in conjunction with that of the suspended solids, is useful for comparative purposes.

For convenient reference, I have shown in the form of a diagram the percentage reduction in free ammonia, albuminoid ammonia, and oxygen absorbed at different stages, the figures for the sewage being taken at 100, and also the actual nitric nitrogen figures in parts per 100,000.



So much, then, for the detailed results of the working of this plant. Whether what has been proved to be possible in this case will be found to be equally possible in other cases remains to be seen, and if the answer be in the affirmative, it is unnecessary to point out that the resulting economy in the construction of filters would be very material. Personally I am extremely optimistic regarding future possibilities in this direction, and only the other day I had an opportunity of practically applying this recent experience with, so far, most gratifying results, in the case of a stronger sewage and one which contains a considerable amount of brewery waste.

In this case the authority had some years ago constructed works which provided for the nitrification of the sewage by means of "contact" beds, and, being lately threatened with proceedings on account of pollution, on the advice of their engineer an experimental plant was constructed, with the view of determining whether better results could be obtained by means of "percolating" filters. Having worked these filters for about seven months, the engineer came to the conclusion that he might safely recommend the adoption of a scheme on similar lines, but with 5-ft. 6-in. filters, to dispose of

the whole of the sewage of the town. Before assenting to this proposal, however, the authority decided to seek further advice, and this led to my being consulted.

Shortly, I may state that the experimental filter in this case had a mean depth of 4 feet, and was formed of clinker broken to sizes varying from $\frac{3}{4}$ to $\frac{1}{2}$ inch, the sewage, after having undergone preliminary treatment, the nature of which need not here be described, being distributed on to the filter by means of a series of fixed sprays. The results obtained were fairly satisfactory as regards nitrification, but the organic matter remaining unconverted was considerable, and the effluent, so far as appearance went, was a poor one, owing to the amount of suspended matter it contained.

In order to determine whether and to what extent the imperfect results were attributable to the comparatively large-sized medium composing the filter, and with the view of ascertaining whether, in the case of the sewage in question, a shallower filter would answer the purpose, I suggested that a section of the filter should be partially reconstructed by removing the top medium to a depth of 12 inches and replacing it by granite chippings broken to $\frac{1}{8}$ inch, and also that a collecting tray should be introduced at a depth of 3 feet in the reconstructed section. This alteration was made, and we thus had the means of comparing the results obtained by the altered section at depths of 3 feet and 4 feet 6 inches with those from the undisturbed section at a depth of 4 feet 6 inches under identical conditions.

Having resumed the working of the filter, at a rate of flow of 200 gallons per square yard per day, three weeks were allowed to elapse for ripening before the first set of samples were collected, and up to the time of writing this paper the experiment, under the altered conditions, had been in operation for four months.

So far I have had an opportunity of analysing two sets of samples from the two sections of the filter, and the following are the means of the more significant results obtained:—

	Parts per 100,000.			
	Septic effluent.	Unaltered section of filter at 4 ft. 6 in. deep.	Altered section of filter at 4 ft. 6 in. deep.	Altered section of filter at 3 ft. deep.
Solids in suspension	9·10	2·10	1·15	1·00
Free ammonia	1·067	0·710	0·250	0·067
Albuminoid ammonia	0·558	0·154	0·107	0·044
Oxygen absorbed in 4 hours at 80° F.	3·157	0·818	0·680	0·388
Nitric nitrogen	Nil	1·04	1·16	2·58

It will be seen that the improvement effected by apparently so trivial an alteration is remarkable. The improved quality of the effluents from the altered section of the filter at a depth of 3 feet compared with those from the same section and the unaltered section at a depth of 4 feet 6 inches is most striking.

With reference to the work done at different depths in filters, Scott-Moncrieff has added very much to our knowledge of the subject by his well-known experiments: on a small scale at Ashtead some eight years ago, and, later, on a larger scale, at Caterham Barracks. The filters were built up of nine trays, each 7 inches deep, with perforated bottoms, and supported vertically over one another with about 3-inch interspaces. The depth of the filtering medium in each tray was 6 inches, giving a total effective depth of 4 feet 6 inches. The medium consisted of coke, broken to pass through a ring 1 inch in diameter, and the rate of delivery was about 200 gallons per square yard (1,000,000 gallons per acre).

The object Scott-Moncrieff had in view was a two-fold one: first, to secure the freest possible aeration of the filter; and, secondly, to separate, as far as possible, the various stages of the process by providing facilities for the differentiation of the colonies of nitrifying organisms. Incidentally the arrangement also allowed of the collecting of samples of effluents for analysis from different depths, for comparative purposes as regards the oxidising changes.

Without going into detail, I may mention that while the nitrification effected by the tray filters was exceptionally high, the changes, notwithstanding the free aeration which the arrangement provided for, did not take place so rapidly, nor at so shallow a depth, as in the case of the Hanley experiments. The nitrous change was more marked, and was continued to a greater depth, and the reduction in the free ammonia, as well as in the oxygen absorbed, was far more gradual. It is true that the sewage was a much stronger one, but, making allowance for this, the work done per foot deep of filtering medium was relatively considerably less than in the case of Hanley. I feel pretty confident that had a much finer filter medium been used by Scott-Moncrieff the high oxidising changes would have been effected at a shallower depth, and practically the whole of the suspended solids would have been liquefied and nitrified within the filter.

Dr. Harriette Chick, in a paper published in the 'Proceedings of the Royal Society,' 1906, B, vol. 77, gives an account of certain laboratory experiments she conducted in 1901, and again in 1903, having reference to the nitrification of sewage. Three cylindrical filters were employed, each $4\frac{3}{4}$ inches in diameter, and approximately $1\frac{1}{2}$, $3\frac{1}{4}$, and $6\frac{1}{2}$ feet in depth respectively. The

filtering material used was coke of practically the same grade as that used at Hanley, and the sewage was delivered on to the filters at the rate of 300 gallons per 24 hours by means of a syphonic discharge on to a perforated distributing disc at intervals of 38 minutes. The sewage dealt with was artificially prepared by diluting liquid cow manure with water, the dilution in the first experiment being 1 in 20 and in the second 1 in 50 to 1 in 100. The suspended solids were removed by rough filtration through glass wool.

In this case, the filters being new, it was possible to determine the stages in the ripening process, and it was found that while a marked amount of general oxidation was apparent in the effluents from all the filters in two weeks, no trace of oxidised nitrogen appeared until 10 days later, and until then the ammonia in the effluents was the same as in the sewage. The first trace of oxidised nitrogen in the effluents appeared in the form of nitrous nitrogen on the following dates, all three filters having been started on February 20th:—

Deep filter on 18th March.
Medium „ 21st March.
Shallow „ 28th March.

For some time the formation of nitrous nitrogen continued in increasing amount, and later, when nitric nitrogen made its appearance, the nitrous nitrogen gradually diminished until ultimately the effluents from the medium and deep filter showed no trace of it. For some reason it would appear that the effluents from the shallowest filter ceased to be recorded before this period.

Regarding the absence of nitrous nitrogen in the effluents after the filters had matured, the results accord with those at Hanley. In one other respect, namely, the reduction of general oxidisable matter, the results also agree with those at Hanley in the fact that practically the reduction was as marked in the shallow as in the deep effluents.

As regards the degree of nitrification at different depths, Dr. Chick's results do not quite compare with those of Hanley. It must be remembered, however, that the conditions differed widely. The volume of sewage dealt with in the former case was relatively greater, and its ammoniacal strength was very much higher. Also the intervals of delivery on to the filter were much longer, namely, 38 minutes compared with 5 minutes in the case of Hanley, and in addition all the disturbing influences incidental to a laboratory experiment of this character have to be taken into account, such as the effect of peripheral capillarity upon the uniformity of the downward flow in a filter of such small diameter. At the same time, the nitrification effected at the medium depth was very considerable, and it would have been interesting to have had another record between that and the 6-ft. 6-in. depth.

It may now be convenient to sum up the arguments which may be adduced, and the conclusions which may be drawn, from the recent observations at Hanley. In the first place, two important factors undoubtedly contributed in no small degree to the high quality of the work done: (1) the small amount of suspended matter in the effluent applied to the filter; and (2) the very efficient means of distribution provided.

The oxidation of organic matter already in solution is a comparatively simple process, but to bring about the liquefaction of suspended organic solids takes longer time, hence the importance of providing, as far as possible, for their removal by mechanical subsidence or other methods, and their liquefaction by anaerobic organisms as a preliminary process. When septic tank treatment was first introduced, its advocates, in their enthusiasm, predicted that the difficult question of sludge disposal would thus be solved, but experience does not quite corroborate this prediction. In the case in point I attribute the satisfactory reduction of suspended solids in the septic tank effluent to the large capacity of the detritus tanks. These were divided into three, two of which were always in use, while the third was emptied for cleansing weekly, and so on in rotation, the whole three being brought into use during rain periods.

As regards the distribution of the sewage on the filter, it is obvious that uniformity is all-important, otherwise certain sections might be greatly overtaxed, while other sections were working much below their capacity. The distribution in this case was so perfect that frequent tests failed to establish any appreciable difference between one square yard of filter and another.

Now, as regards the rapidity of the oxidising changes, and the remarkable purity of the effluent after filtration through 12 inches only. The three essential factors in the final changes are time, air, and organisms, and, given a sufficiency of air, the greater the number of organisms present the larger the amount of work done, provided the organic matter both in solution and suspension is brought into intimate contact with the organisms. The factor which governs the bacterial population is the area available for growth, and this may be increased by two methods, either by enlarging the cubic capacity of the filter or by subdividing the filtering medium. In the case in point, the latter was the expedient adopted, and the subdivision was carried as far as it was thought possible to carry it without preventing the superficial penetration of the suspended solids into the interstices. In view of the results, it is needless to discuss whether the reduction in the size of particles resulted in an inadequate air supply.

The relative amount of carbonic acid in the air of the filter at different depths also shows the highly active oxidising changes which take place in

the superficial layers. A series of samples of air aspirated from different depths, by means of iron tubes driven vertically into the body of the filter while in continuous use, yielded the following mean results:

Carbonic Acid in parts per 1000.

1 ft.	2 ft.	3 ft.	4 ft.
19·5	21·5	20·0	20·0

An interesting fact bearing upon the aeration of the filter was incidentally made apparent by the method at first adopted of collecting the air. The distributor passing backwards and forwards over the filter was found to interfere considerably with the collection of the samples, and, to obviate this, the apparatus was periodically stopped for varying periods during the operation. Owing, however, to extraordinary discrepancies in the results thus obtained, measures were taken to overcome this difficulty and enable the air to be collected without interrupting the regular flow of sewage on to the filter. The results, of which the figures just given are the means, were then found to be remarkably uniform, whereas in the case of the earlier samples the carbonic acid varied in amount according to the intervals which elapsed between the stopping of the distributor and the collection, short though these intervals were, from 2·8 to 26·1, showing how free was the current of air through the filter.

If, then, by using fine-grade particles the depth of filter may be greatly reduced, the resulting economy would dictate such a course, but there is another important consideration which, other things being equal, tells in favour of shallow filters from the point of view of aeration. The air travels through a filter from above downwards, the direction of the current probably being mainly due to the percolation downwards of the sewage, and its more rapid flow along the effluent drains. The air, therefore, as it passes downwards, carries with it the products of the combustion which has taken place above, and thus has an asphyxiating effect upon the organisms below, and it is possible that even anaerobic fermentation may be revived in the bottom layers. The sudden increase in the free ammonia figure, noted in the case of the effluent from the lowest tray, may possibly be accounted for in this way, because the albuminoid ammonia figure does not represent the total organic nitrogen present, therefore there is an unrecorded margin of nitrogenous organic matter available for the revival of the ammonia change should this explanation of the phenomenon be the correct one.

Be this as it may, however, the phenomenon does not appear to be accounted for by fouling of the deeper strata. At the end of the observations the filter was opened and carefully examined throughout its

depth, when it was found that the dark discoloration from deposit was confined to the surface, as was evident from the untarnished appearance of the light-coloured filtering medium below the top 14 to 18 inches. Also, the relative amount of organic solids in the interstices at different depths, ascertained by drying and igniting 10 grammes of the filter particles in each case, supports this contention, as the following figures show:—

Percentage Loss on Ignition of Filter Particles at Different Depths.

6 in.	1 ft.	2 ft.	3 ft.	4 ft.
3·25	0·99	0·65	0·53	0·53

I may mention that on ignition there was practically no smell, except in the case of the samples collected at the 6-inch and 1-foot depths, and that in the case of these only an odour such as that of burning soil could be detected.

Apart from all theory, however, the fact has been established beyond all doubt that, in the case of the sewage in question at any rate, the lower or 3 feet of filter medium is absolutely unnecessary, and, so far as the cost of construction of the filter is concerned, the expenditure might be reduced by about one-half. Again from the point of view of cost, another important consideration comes in. It frequently happens that the absence of 2 or 3 feet of available fall is the determining factor between a gravitation and pumping scheme, and in this respect the reduced depth of filter might lead to further economy, not only in capital outlay, but in maintenance charges.

Now, the question may be asked whether this experience acquired at Hanley may be applied in other cases where the sewage may be of a stronger character? I am not at present in a position to give a positive answer to that question, but if, as is probable, such should prove not to be the case, the observations I have recorded clearly point to the conclusion that the extra filtering capacity should be provided for by increasing the area rather than the depth of the beds. The three factors in the nitrifying process being a given time, a given volume of air, and a given bacterial population, all these would be supplemented by extending the area in accordance with the combustion which has to be effected, and thereby diminishing the delivery per square yard of filter. Of course, I do not suggest that the depth of filters may be reduced to 1 foot, because we must allow for the effluent drains, and the few inches of large material immediately on the top of them, but I do suggest the practicability, if a fine medium is used, of reducing the total depth to, say, 2 feet 6 inches.

The tables appended give the details of the analyses and other determinations made during the investigations which have been described.

Crude Sewage. Parts per 100,000.

1905.	July 6.	July 13.	July 20.	Aug. 24.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	162·8	—	189·0	142·4	167·0	156·4	147·5	—	239·2	155·5	187·9	199·3	156·0	172·0	162·5	162·4	167·9	166·8
Solids in suspension ...	—	—	—	46·0	66·2	43·8	43·0	—	133·0	53·2	74·8	65·8	47·7	78·5	62·1	51·7	63·2	60·5
,, organic	—	—	—	19·0	33·0	18·5	22·0	—	35·8	23·8	37·8	34·2	20·3	41·8	30·8	23·4	30·9	29·0
,, mineral	—	—	—	27·0	33·2	25·3	21·0	—	97·2	29·4	37·0	31·6	27·4	36·6	31·2	28·3	32·3	31·5
Chlorine	9·2	11·2	10·6	13·6	12·4	11·8	10·8	10·2	11·2	12·4	11·8	11·2	9·6	12·6	8·8	10·8	11·4	9·4
Free ammonia	1·516	2·376	3·288	1·666	1·668	1·656	2·220	2·880	2·544	2·180	2·240	2·350	1·904	3·148	2·120	1·674	1·600	1·750
Albuminoid ammonia	0·824	0·828	1·084	1·030	0·844	0·710	0·850	1·068	1·704	0·592	0·916	1·532	0·724	0·846	0·890	0·880	1·086	1·096
Oxygen absorbed in 4 hours at 80° F.	3·400	4·840	5·564	4·736	4·034	3·900	4·834	4·867	6·667	4·234	5·813	5·300	4·500	5·157	4·657	6·20	5·800	5·844
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	—	1·626	1·613	1·700	1·667	1·734	2·220	2·434	1·800	2·188	2·00	1·234	1·813	1·782	1·970	1·800	2·219
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	—	—	2·867	2·034	1·634	2·000	2·967	1·667	1·875	1·407	1·700	2·634	3·157
Nitric nitrogen on day of collection	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·25	—	0·10
Nitric nitrogen day after collection	Nil	Nil	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	0·95	0·47	0·39	0·10
Nitrous nitrogen on day of collection	—	0·022	0·022	0·04	0·03	0·018	0·007	,,	0·09	0·09	0·02	0·03	0·018	0·029	0·014	0·011	0·025	Nil
Nitrous nitrogen day after collection	—	Nil	Nil	Nil	Nil	Nil	0·007	,,	0·114	0·129	0·051	0·007	0·062	0·04	0·014	0·03	0·06	,,
Column necessary to obscure test lines (inches)	0·5	0·5	0·75	0·75	0·75	0·5	1·0	0·5	0·25	0·5	0·5	0·5	0·5	0·5	0·5	0·75	0·5	0·25

Detritus Tank Effluent. Parts per 100,000.

1905.	Aug. 24.	Aug. 31.	Sept. 7.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	123·0	131·5	141·9	122·4	86·1	116·4	121·8	107·8	104·1	107·2	141·1	116·9	115·7
Solids in suspension	26·0	22·6	23·1	17·1	19·2	19·6	16·3	13·4	10·68	10·6	8·2	17·8	16·9
,, organic	10·6	8·1	8·1	11·3	9·2	8·7	1·9	2·2	4·64	5·3	1·8	8·8	8·8
,, mineral	15·4	14·5	15·0	5·8	10·0	10·9	14·4	11·2	6·04	5·3	6·4	9·0	8·1
Chlorine	15·8	13·4	11·8	9·6	8·0	9·4	9·0	8·6	7·6	9·0	9·2	9·8	9·2
Free ammonia	2·176	1·742	1·990	2·100	1·692	2·000	1·368	1·476	0·960	1·428	0·816	1·600	2·018
Albuminoid ammonia	0·802	0·556	0·846	0·592	0·330	0·444	0·218	0·290	0·245	0·318	0·348	0·604	0·726
Oxygen absorbed in 4 hours at 80° F.	3·484	3·434	3·700	2·700	2·500	2·344	2·400	1·467	1·719	1·938	2·334	3·634	3·782
Oxygen absorbed in 3 mins. before incubation at 80° F.	1·355	1·267	1·434	0·867	1·000	0·813	0·867	0·534	0·688	0·625	1·067	0·867	1·294
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	1·000	1·000	0·969	1·000	1·500	0·594	0·688	1·134	1·634	1·438
Nitric nitrogen on day of collection	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·25	—	0·09
,, ,, day after collection	,,	,,	,,	,,	,,	,,	,,	,,	,,	0·42	0·25	0·42	0·09
Nitrous nitrogen on day of collection	0·03	0·029	0·01	,,	,,	0·01	0·02	0·007	0·01	0·01	0·007	0·02	0·02
,, ,, day after collection	Nil	Nil	Nil	,,	0·059	Nil	0·077	0·040	0·062	0·011	0·02	0·04	0·014
Column necessary to obscure test lines (inches)	1·25	1·25	1·0	1·25	1·5	1·5	1·75	1·5	2·5	2·75	2·0	1·5	1·25

Septic Tank Effluent. Parts per 100,000.

1905.	July 13.	July 20.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	—	126·7	94·2	102·5	100·5	—	99·4	98·1	108·4	117·5	102·0	108·3	115·7	113·6	110·8	112·2
Solids in suspension	—	—	2·6	5·4	12·0	—	2·9	7·6	10·0	7·4	9·6	10·8	6·7	6·3	8·8	8·6
,, organic	—	—	0·7	0·3	6·6	—	1·3	5·7	5·5	2·0	3·8	7·0	3·5	3·7	5·3	4·8
,, mineral	—	—	1·9	5·1	5·4	—	1·6	1·9	4·5	5·4	5·8	3·8	3·2	2·6	3·5	3·8
Chlorine	9·8	10·8	8·6	10·0	9·2	9·4	10·6	10·0	9·8	10·6	11·2	9·6	8·8	10·2	9·8	10·0
Free ammonia	1·684	2·592	1·214	1·706	1·538	2·268	1·584	2·076	1·036	1·882	2·020	1·614	1·650	1·090	1·492	2·024
Albuminoid ammonia	0·208	0·296	0·224	0·394	0·358	0·320	0·286	0·238	0·265	0·300	0·290	0·374	0·354	0·336	0·476	0·734
Oxygen absorbed in 4 hours at 80° F.	1·968	2·188	1·834	2·267	1·080	2·667	1·734	1·967	1·813	2·470	2·367	2·157	1·625	2·434	2·667	3·719
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	0·814	0·634	1·134	0·800	1·100	0·567	0·934	0·688	0·867	0·834	0·782	0·657	0·800	0·834	1·094
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	1·834	0·967	1·234	1·313	2·667	1·334	1·625	1·407	1·900	0·967	2·032
Nitric nitrogen on day of collection	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, day after collection	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	0·30	0·55	,,	,,	0·50
Nitrous nitrogen on day of collection	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	Nil	Nil	,,	,,	Nil
,, ,, day after collection	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Column necessary to obscure test lines (inches)	1·5	1·25	1·75	1·25	1·5	1·25	2·0	1·5	2·0	1·75	1·5	1·5	2·5	1·5	1·5	1·0

Filter Effluent, 1 foot below Surface. Parts per 100,000.

1905.	July 13.	July 20.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	—	—	93·7	116·0	92·5	—	95·0	92·3	101·4	104·3	92·9	97·0	113·7	110·1	105·5	105·2
Solids in suspension	—	—	—	0·6	0·0	—	Nil	Nil	0·4	Nil	Nil	Nil	Nil	Nil	2·0	Nil
,, organic	—	—	—	0·2	0·0	—	,,	,,	0·2	,,	,,	,,	,,	,,	1·6	,,
,, mineral	—	—	—	0·4	0·0	—	,,	,,	0·2	,,	,,	,,	,,	,,	0·4	,,
Chlorine	9·6	11·0	8·4	9·4	9·0	9·6	10·0	9·8	9·0	10·2	8·6	9·2	8·8	9·0	9·0	10·0
Free ammonia	0·021	0·012	0·017	0·009	0·008	0·003	0·022	0·006	0·006	0·048	0·010	0·028	0·240	0·016	0·056	0·083
Albuminoid ammonia	0·038	0·035	0·057	0·027	0·034	0·041	0·039	0·053	0·027	0·033	0·029	0·048	0·069	0·086	0·158	0·061
Oxygen absorbed in 4 hours at 80° F.	0·336	0·276	0·268	0·280	0·336	0·308	0·308	0·308	0·276	0·336	0·268	0·352	0·312	0·456	0·440	0·388
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	0·100	0·108	0·080	0·096	0·056	0·040	0·096	0·076	0·096	0·068	0·100	0·100	0·120	0·160	0·128
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	0·056	0·056	0·040	0·064	0·080	0·068	0·100	0·028	0·108	0·136	0·000
Nitric nitrogen on day of collection	—	1·75	1·55	2·12	1·69	2·12	1·25	2·04	1·61	1·43	1·67	1·92	1·00	1·72	1·33	1·49
,, ,, day after collection	2·08	2·08	1·54	1·43	1·43	2·00	3·30	2·86	2·22	2·31	2·00	1·82	2·63	1·67	2·38	1·43
Nitrous nitrogen on day of collection	0·01	0·009	Nil	0·005	Nil	0·005	Nil	Nil	Nil	0·007	Nil	Nil	Nil	Nil	Nil	0·014
,, ,, day after collection	0·01	0·007	0·009	Nil	,,	Nil	,,	,,	,,	0·007	,,	,,	,,	,,	0·000	0·014
Column necessary to obscure test lines (inches)	14·0	22·0	16·0	Over 2′	Over 2′	Over 2′	Over 2′	19·0	Over 2′	Over 2′	Over 2′	2′	15·0	11·0	7·5	21·0

Filter Effluent, 2 feet below Surface. Parts per 100,000.

1905.	July 13.	July 20.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	—	119·5	96·3	89·2	93·5	—	96·8	92·5	101·8	104·9	94·6	93·3	114·4	110·2	104·1	105·2
Solids in suspension	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1·0	Nil
,, organic	—	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	0·6	,,
,, mineral	—	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	0·4	,,
Chlorine	9·8	11·0	8·6	9·0	9·4	9·6	10·3	9·8	9·6	10·2	8·8	9·2	8·8	9·6	9·0	9·8
Free ammonia	0·024	0·039	0·016	0·007	0·015	0·006	0·022	0·009	0·006	0·012	0·012	0·005	0·130	0·006	0·007	0·011
Albuminoid ammonia	0·045	0·039	0·038	0·023	0·024	0·036	0·028	0·034	0·019	0·026	0·025	0·046	0·045	0·062	0·072	0·043
Oxygen absorbed in 4 hours at 80° F.	0·416	0·328	0·280	0·216	0·256	0·240	0·280	0·280	0·216	0·268	0·216	0·288	0·264	0·348	0·360	0·328
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	0·128	0·080	0·056	0·056	0·080	0·028	0·080	0·076	0·080	0·068	0·076	0·056	0·096	0·120	0·088
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	0·040	0·040	0·040	0·052	0·068	0·056	0·064	0·052	0·096	0·096	0·064
Nitric nitrogen on day of collection	—	1·81	1·72	2·00	1·82	2·00	1·39	3·33	1·67	1·82	1·88	2·00	1·25	1·92	1·18	1·49
,, ,, day after collection	1·72	2·12	2·22	1·43	1·67	2·70	2·50	2·50	2·75	2·00	1·92	2·12	2·20	1·43	1·67	0·90
Nitrous nitrogen on day of collection	0·08	0·05	0·01	0·01	0·01	0·007	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, day after collection	0·07	0·059	0·02	0·01	Nil	Nil	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Column necessary to obscure test lines (inches)	5·0	4·5	13·0	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	14·0	10·5	Over 2′

Filter Effluent, 3 feet below Surface. Parts per 100,000.

1905.	July 13.	July 20.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	—	122·2	95·0	90·1	94·7	—	99·1	94·0	105·7	100·6	96·9	92·1	116·8	111·0	104·1	103·9
Solids in suspension	—	—	—	Nil	1·6	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·1	Nil
,, organic	—	—	—	,,	0·6	—	,,	,,	,,	,,	,,	,,	,,	,,	0·1	,,
,, mineral	—	—	—	,,	1·0	—	,,	,,	,,	,,	,,	,,	,,	,,	Nil	,,
Chlorine	9·8	11·0	8·6	9·0	9·0	9·6	10·2	10·0	9·3	10·0	9·0	9·2	9·0	9·2	9·0	9·8
Free ammonia	0·013	0·005	0·006	0·007	0·004	0·029	0·012	0·004	0·005	0·004	0·008	0·004	0·025	0·006	0·009	0·003
Albuminoid ammonia	0·045	0·028	0·021	0·023	0·024	0·026	0·034	0·025	0·016	0·021	0·021	0·038	0·027	0·062	0·043	0·042
Oxygen absorbed in 4 hours at 80° F.	0·336	0·264	0·216	0·216	0·268	0·256	0·256	0·256	0·200	0·216	0·188	0·216	0·188	0·256	0·296	0·276
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	0·064	0·068	0·028	0·056	0·068	0·028	0·056	0·064	0·068	0·056	0·064	0·052	0·056	0·096	0·076
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	0·040	0·056	0·040	0·052	0·056	0·040	0·052	0·028	0·080	0·080	0·052
Nitric nitrogen on day of collection	—	2·00	1·82	2·17	2·17	1·67	1·67	2·17	1·67	1·67	1·54	2·00	1·43	2·00	1·27	1·00
,, ,, day after collection	1·05	2·50	2·00	1·88	1·85	1·61	2·63	2·00	2·17	2·23	1·82	1·54	2·63	1·32	1·47	1·00
Nitrous nitrogen on day of collection	0·066	0·022	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, day after collection	0·12	0·018	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Column necessary to obscure test lines (inches)	7·5	6·5	Over 2′	Over 2′	20·0	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′

Filter Effluent, 4·5 feet below Surface. Parts per 100,000.

1905.	July 13.	July 20.	Aug. 31.	Sept. 7.	Sept. 15.	Sept. 21.	Oct. 9.	Oct. 13.	Oct. 19.	Oct. 26.	Nov. 2.	Nov. 10.	Nov. 17.	Dec. 7.	Dec. 14.	Dec. 21.
Total solids	—	124·7	95·0	93·8	94·2	—	95·0	96·1	110·8	104·8	91·3	98·0	122·7	119·6	105·1	112·8
Solids in suspension	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, organic	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, mineral	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chlorine	9·8	10·8	8·8	9·4	9·2	9·6	10·2	10·0	9·6	10·2	9·0	9·0	8·8	9·2	9·2	9·8
Free ammonia	0·075	0·097	0·027	0·031	0·018	0·029	0·018	0·023	0·009	0·096	0·031	0·026	0·092	0·035	0·040	0·043
Albuminoid ammonia	0·032	0·039	0·019	0·022	0·023	0·026	0·026	0·029	0·021	0·025	0·029	0·027	0·024	0·040	0·027	0·029
Oxygen absorbed in 4 hours at 80° F.	0·336	0·300	0·188	0·228	0·256	0·256	0·240	0·240	0·200	0·256	0·228	0·316	0·344	0·268	0·228	0·264
Oxygen absorbed in 3 mins. before incubation at 80° F.	—	0·128	0·068	0·040	0·068	0·068	0·028	0·068	0·064	0·080	0·056	0·076	0·130	0·040	0·040	0·100
Oxygen absorbed in 3 mins. after incubation (3 days) at 80° F.	—	—	—	—	—	0·040	0·040	0·028	0·052	0·068	0·056	0·064	0·00	0·056	0·028	0·00
Nitric nitrogen on day of collection	—	1·56	1·72	1·55	1·82	1·67	1·54	2·17	1·33	1·33	1·25	1·67	1·92	2·86	1·51	1·67
,, ,, day after collection	1·82	2·08	1·82	1·15	1·54	1·61	2·23	2·22	2·50	1·67	1·72	1·88	4·36	2·50	1·35	1·43
Nitrous nitrogen on day of collection	Nil	0·011	Nil	0·003	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·011	0·011	0·018	0·022
,, ,, day after collection	Trace	0·007	,,	Nil	,,	,,	,,	,,	,,	0·00	,,	,,	Trace	0·011	0·003	0·014
Column necessary to obscure test lines (inches)	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	Over 2′	8·0	16·0	20·0	22·0