ammonio silver nitrate in a similar manner to the others gave on analysis:—silver, 36·18 and 36·35; nitrogen, 25·65 and 25·63 per cent. Calculated for

$(C(NO_2)_3NHAg)3NH_3$, Ag 35·9, $N_2$ 25·7 per cent.

Molecular weight determination (boiling point) in acetone gave results distinctly confirmatory of the above formula, but ammonia seems to be split off from these compounds by long heating in acetone or alcohol. All these substances explode or burn rapidly when heated and are also sensitive when dry to percussion or friction.

Beyond the analyses and ebullioscopic molecular weight determination, no proof of the above formula is at present put forward.

## Manchester Section.

*Meeting held at the Grand Hotel on Friday, April 3rd, 1914.*

MR. J. H. HOSEASON IN THE CHAIR.

### EXPERIMENTS ON THE OXIDATION OF SEWAGE WITHOUT THE AID OF FILTERS.

BY EDWARD ARDERN, M.SC., AND WILLIAM T. LOCKETT, M.SC.

It has long been known that if sewage be exposed to the air for a sufficient period of time, the organic contents are gradually oxidised, with the formation of a deposit of so-called "humus" and the final production of nitrate from the ammonium salts and the nitrogenous organic matter.

This purification change of which the course of the reaction has been so carefully studied and thoroughly worked out by Adeney in his researches on behalf of the Royal Commission on Sewage Disposal, takes place, however, comparatively slowly, and even if aided by direct aeration, by no means becomes a practical method of sewage purification.

Numerous investigators have from time to time endeavoured to utilise aeration methods in the practical solution of the sewage problem, but until quite recently without any reasonable amount of success.

Among the earlier investigations may be mentioned those of Dupré and Dibdin[1] on the aeration of London Sewage, and those of the Massachusetts State Board of Health relating to the use of aeration in the filtration of sewage through gravel and sand filters. Dr. Drown,[2] chemist to this Board, concluded from the results of a series of experiments, that the oxidation of organic matter in water was not hastened by vigorous agitation with air.

Waring[3] of the United States was one of the first to apply aeration methods in the purification of sewage on a working scale.

In 1886 Hartland patented an aeration chamber for the purification of sewage or tank effluent, which Kaye Parry[4] employed in experiments undertaken in 1887, while in 1892 Lowcock conducted experiments on the aeration of filter beds by a forced air supply.

In the latter year Mason and Hine[5] published the results of a research on the aeration of mixture of sewage and water in which they concluded that aeration had but little oxidation effect on the sewage.

In 1897 Fowler[6] investigated the effect of aeration on the effluent resulting from the chemical precipitation of Manchester sewage, without any very tangible results being obtained, at any rate so far as the total amount of oxidation was concerned.

It would thus appear that the results of the earlier investigations on the subject of aeration of sewage, indicated that aeration *per se* could not be considered as a practicable adjunct in the process of sewage purification.

Recently, however, the subject has been reopened by the work of Black and Phelps, Clark, Gage and Adams, and Fowler and Mumford.

In dealing with the question of the pollution of the New York Harbour, Black and Phelps[7] studied the possibilities of the application of aeration to the treatment of sewage.

Their experiments dealt with the aeration of both fresh and partially septicised sewage, in various types of tanks and it was shown that under certain conditions it was possible by means of a reasonable amount of aeration to remove the more readily putrescible matters from the sewage and thereby to a certain extent increase its stability.

Black and Phelps were so far convinced of the practicability of such methods of treatment of sewage, as to recommend that the sewage from a certain section of the New York area should be dealt with on these lines, prior to discharge into the waters of the harbour.

In the Annual Report of the Massachusetts State Board of Health for the year 1912, published at the end of 1913, is described an investigation by Clark and De M. Gage on the possibilities of the use of aeration for preliminary treatment of sewage prior to filtration. They found that simple aeration of sewage for 24 hours reduced the free and albuminoid ammonia to some extent and that with sewage which was both aerated and seeded with green growths—*Protococcus* and *Scenedesmus*—the albuminoid ammonia was even more noticeably reduced. Later it was found that appreciable nitrification was obtained within 24 hours in the aerated sewage containing the green growths.

Subsequently Clark and Gage found that aeration for a much shorter period, in a tank containing slabs of slate about one inch apart, covered with a compact brown growth of sewage matters, was sufficient to coagulate the sewage colloids, and thus to produce a well clarified non-nitrified effluent capable of satisfactory filtration at several times the normal rate.

Later Fowler and Mumford[8] carried out experiments on the action in the presence of air, of an organism designated "M7" (isolated by Mumford from ponds receiving water discharged from a colliery) on sewage containing a certain proportion of iron salts.

This organism has the property of precipitating the iron as ferric hydroxide from solutions of iron salts.

In the paper referred to, it is stated that sewage (in presence of a certain quantity of iron salts) inoculated with this organism, can be thoroughly clarified by six hours aeration. The resultant effluent after settlement of the separated organic colloids, was quite clear and practically free from colloids. It is further stated that although the ordinary methods of analysis failed to reveal the extent of the change effected by the above treatment, the effluent after aeration was always non-putrefactive on incubation, and could be readily oxidised and nitrified by filtration at a high rate.

In quite a recent publication Clark and Adams[9] give the results obtained during 12 months operation of the specially constructed tank used in their earlier experiments previously referred to.

It is shown that a rather better coagulation of the organic colloids and purification of the sewage generally, can be obtained by means of aeration for a period of five hours, under the conditions of experiment, than is obtained by efficient chemical precipitation, and at a considerably reduced cost.

The effluent resulting from the aeration treatment was applied to trickling filters 10 feet deep, at rates varying from 8 to 10 million gallons per acre per day, with the production of a well-nitrified and thoroughly stable filtrate.

In connection with the experiments carried out by Clark and his colleagues, it should be mentioned that the sewage treated was considerably more dilute than the

[1] Report to Royal Commission on the Metropolitan Sewage Disposal, 1884, Vol. 2.
[2] Clark and Adams, Engineering Record, February 7th, 1914, p. 158.
[3] Rafter and Baker, 1894, Sewage Disposal in the United States, p. 535.
[4] Trans. Inst. C.E. Ireland, Vol. XX., 1888.
[5] Journ. Amer. Chem. Soc., Vol. 14, p. 7.
[6] Annual Report, 1897, Rivers Dept., Manchester Corporation.
[7] Mass Inst. of Technology. Contributions from the Sanitary Research Laboratory, Vol. VII., Boston, Massachusetts, 1911.
[8] Journal of Roy. San. Inst., November, 1913.
[9] Engineering Record, February 7th, 1914, p. 158.

majority of English sewages, as will be seen from the following average analytical returns taken from the paper quoted.

| | Parts per 100,000. |
|---|---|
| Oxygen consumed | 3·52 |
| Free and saline ammonia | 3·62 |
| Albuminoid ammonia | 0·57 |

The researches of Clark, Gage, and Adams, and of Fowler and Mumford, show a marked advance on previous work, but it will be seen that in the case of the former investigators the idea of surface contact is retained, as evidenced by the construction of the aeration tank, and that in order to produce a nitrified and stable effluent, further treatment in filters is still required.

With regard to the method of treatment suggested by Fowler and Mumford, while the clarification is effected in the absence of surface contacts, the questions of inoculation and the addition of iron salts are introduced and the provision of filters for the rapid treatment of the clarified effluent remains.

In a previous communication to this section of the Society[10] in regard to the effect of the waste liquor from sulphate of ammonia plants on the oxidation of sewage, the present authors, in conjunction with Dr. Fowler, gave some results of the direct aeration of sewage.

It was noted that while some coagulation of the colloid matter took place in the course of twenty-four hours aeration, a period of several weeks elapsed before nitrification was complete.

algal growth. Dr. Fowler suggested that new work might with advantage be carried out on somewhat similar lines.

Acting on this suggestion, further investigations with regard to the subject of aeration of sewage, were undertaken by the authors.

An account of the results which have so far accumulated is given in the following paragraphs.

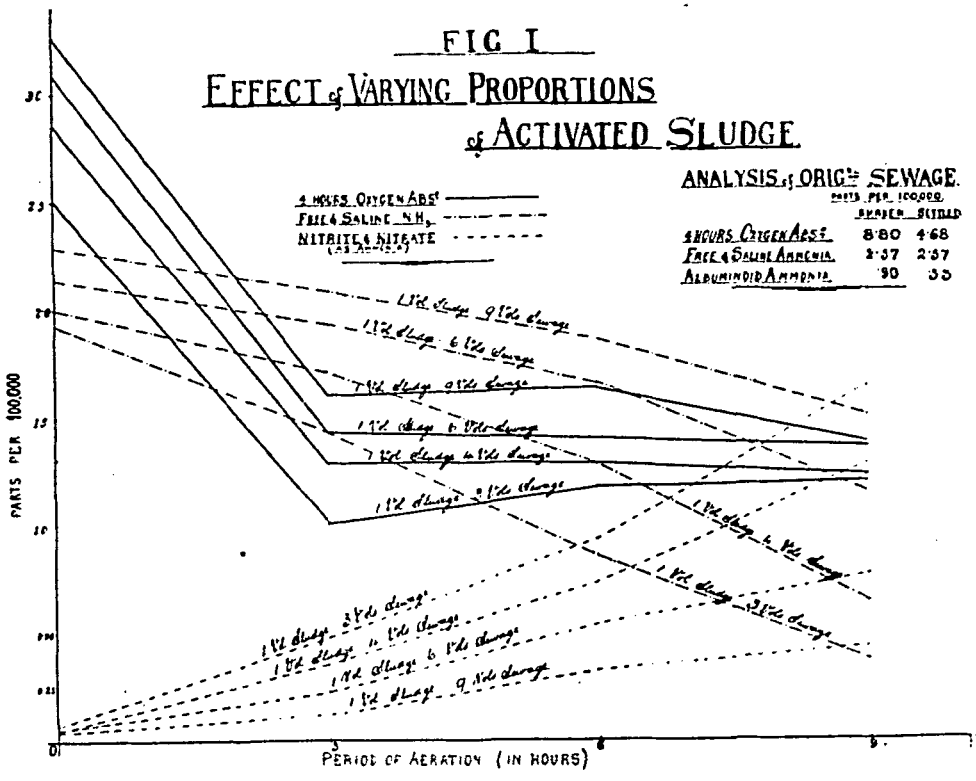
*Preliminary experiments.*

In a series of preliminary experiments, samples of Manchester raw sewage, contained in bottles of 80 oz. capacity, were aerated until complete nitrification ensued; the aeration being effected by drawing air through the sewage by means of an ordinary filter pump.

In the case of the first experiment, about five weeks' continuous aeration was required in order to obtain complete nitrification, as had been previously observed. At the end of this period the clear oxidised liquid was removed by decantation, and a further sample of raw sewage aerated in contact with the original deposited matter, until the sewage was again completely nitrified.

This method of treatment was repeated a number of times with the retention in each case of the deposited solids.

It was found that as the amount of the deposited matter increased, the time required for each succeeding oxidation gradually diminished until eventually it was




In November, 1912, Dr. Fowler visited the States in connection with the question of the pollution of the New York Harbour. Shortly after his return he described to the authors a laboratory experiment which he had seen in progress at the Lawrence Experiment Station, Massachusetts, which evidently referred to the earlier work of Clark and his colleagues on the aeration of sewage in the presence of green organisms, as the bottle in which the sewage was aerated was coated inside with strands of

possible to completely oxidise a fresh sample of crude sewage within twenty-four hours.

For reference purposes and failing a better term, the deposited solids resulting from the complete oxidation of sewage have been designated "activated sludge." Reference to its general characteristics, chemical composition and biological contents will be made later.

As a result of these preliminary experiments the following observations may be made:—

(*a*) In order that the final nitrification change may proceed without hindrance, it is necessary that the alkalinity or basicity of the sewage should be rather more

[10] This Journal, No. 10, Vol. XXXI., 1912.

than equal to the nitric acid resulting from nitrification of the ammonium salts. In some cases it has consequently been found necessary to add a small quantity of alkali prior to complete nitrification.

(*b*) It is essential that the activated sludge should be kept in intimate contact with the sewage during aeration.

This point is illustrated by an experiment, the results of which are given in Table 1 from which it will be seen that while the initial effect on the oxidisable matters as measured by the oxygen absorption test, is not materially affected, on further aeration a marked improvement is shown in the case where the activated sludge is kept in intimate contact with the sewage, than where such conditions do not obtain. Further, in regard to the amount of nitrification very much greater differences are to be observed. This is of considerable importance, as it will be seen from later experiments that the maintenance of the activity of the sludge is considerably influenced by the extent to which the oxidation is carried.

(*c*) That the relation of the volume of the activated sludge to the volume of sewage treated is of importance, more especially in regard to the rate of nitrification.

This latter point is clearly shown by the results of an experiment which was actually carried out much later on in the course of this investigation and which are given on Table 1a (p. 526) and plotted in Figure 1.

It will be seen from this table and diagram that while apart from the dilution effect, the reduction in the amount of oxidisable matter is not seriously affected by the varying proportions of activated sludge, the amount and rate of nitrification are influenced in a marked degree.

*Oxidation of Manchester sewage.*

Once having accumulated a sufficient volume of activated sludge in the manner previously described, a series of determinations were made of the effect of aeration in contact with the sludge, of various samples of the Manchester sewage received at Davyhulme.

In general a proportion of one volume of activated sludge to four volumes of sewage was taken, although in the earlier experiments a much smaller proportion of sludge was employed.

A number of typical results are recorded in Table 2. In each of the experiments quoted the samples of sewage taken are twenty-four hours average samples.

Reference to this table will show that an extraordinarily high degree of purification can be obtained within a reasonable period of time by aeration in contact with the activated sludge.

On the average, aeration under the conditions of experiment for a period of six hours, with subsequent settlement, is sufficient to obtain a percentage purification as measured by the four hours Oxygen Absorption and Albuminoid Ammonia Tests, quite equal to that yielded by efficient bacterial filters. In all cases the resultant effluent is non-putrefactive on incubation.

The amount of nitrification obtained during this period depends to a certain extent on the concentration or strength of the sewage dealt with. In several instances, when treating wet weather sewage, six hours' aeration has been found sufficient to completely oxidise the ammonia present (see Table 2, Expt. No. 30). With average strength Manchester sewage the free and saline ammonia content is entirely removed in from 10 to 18 hours' aeration.

It should be mentioned that all the experiments have been worked on the fill and draw method, and it may be reasonably anticipated that equally good results would be obtained with a less aeration period, when working on a continuous flow system.

Outdoor experiments are being commenced in which a continuous flow of a mixture of sewage and activated sludge will be passed through an aeration chamber.

*Course of reaction.*

In all cases it has been noted that there is a rapid initial effect on the oxidisable matters both colloidal, etc., and crystalloidal, with the production in a period of about three hours of a well-clarified effluent.

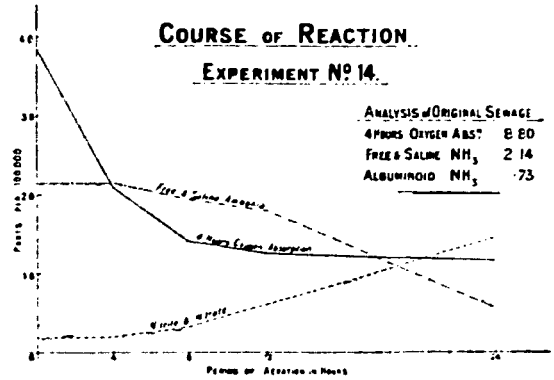
The later stages of the aeration are largely confined to the nitrification of the ammonium compounds.

In order to clearly illustrate this course of the reaction the results of an early experiment (see Table 2, p. 527, Exp. 14) are quoted, in which a small proportion only of activated sludge was employed, as in the later experiments with an increased proportion of sludge the first change occurs rapidly and consequently nitrification is established so early as to partially mask the course of the reaction.

The results of this experiment are plotted in Fig. 2 from which it will be seen that the purification change follows on the lines demonstrated by Adeney.

In view of this fact it was thought of interest to endeavour to sectionise the purification process into (*a*) a

FIG II




carbonaceous fermentation and (*b*) a nitrification process, with the idea of comparing the results with those obtained by the orginal method of working.

*Attempt to sectionise the oxidation process.*

For the purpose of this experiment a partially activated sludge was taken, which while it was capable of effecting the first change, *i.e.*, the removal of the oxidisable matter did not actively promote nitrification.

Three large bottles were used.

(1) Containing a certain volume of this partially activated sludge ($\alpha$ sludge).

(2) ($\beta$ sludge) and (3) ($\alpha\beta$ sludge) Containing a similar volume of thoroughly activated sludge which had been proved capable of vigorously promoting nitrification.

The experiment was carried out in the following manner. Equal volumes of the same sample of sewage were introduced into bottles Nos. 1 and 3 and aeration commenced. At the end of two hours' aeration the contents of bottle No. 1 were allowed to settle for two hours and the supernatant liquor was decanted into bottle No. 2. Another sample of sewage was then added to bottle No. 1 and aeration resumed. After a further two hours' aeration the contents of each of the bottles were allowed to settle for two hours.

In this manner an effluent was obtained from bottle No. 2 which had received two hours' aeration in contact with the partially activated ($\alpha$) sludge and a further two hours' aeration in contact with actively nitrifying ($\beta$) sludge, and from bottle No. 3 an effluent which had been aerated for six hours in contact with thoroughly activated ($\alpha\beta$) sludge.

This method of operation was repeated as often as was reasonably practicable within the twenty-four hours, with the result that the partially activated sludge and nitrifying sludge (bottles Nos. 1 and 2) dealt with three volumes of sewage each working day, as compared with the two volumes treated by the thoroughly activated sludge.

The results obtained during the course of this experiment are given in Table 3 (p. 528).

Reference to this table will show that there was no very material difference in the effluents yielded by the two methods of working.

At the same time it will be seen that the results with the ordinary activated sludge show a marked deterioration as compared with those previously obtained, particularly in regard to the amount of nitrification.

TABLE I.

*Effect of "Intimate" Contact.*

| Results in parts per 100,000. | Experiment 7(a). | | | | | | | | Experiment 8(a). | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 Hours oxygen absorption. | | Free and saline ammonia. | | Albuminoid ammonia. | | Nitrite and nitrate. | | 4 Hours oxygen absorption. | | Free and saline ammonia. | | Albuminoid ammonia. | | Nitrite and nitrate. | |
| | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. |
| Original..... | 3·88 | 4·06 | 2·71 | 2·71 | ·33 | ·33 | | | 5·20 | 5·31 | 2·43 | 2·36 | ·47 | ·485 | ·07 | ·07 |
| After 4 hours aeration | 2·46 | 1·77 | 2·71 | 2·50 | ·215 | ·145 | | | 2·90 | 2·90 | 2·36 | 2·28 | ·30 | ·29 | ·17 | ·15 |
| After 24 hours aeration | 1·26 | ·60 | 2·57 | ·15 | ·105 | ·05 | nil | 1·72 | 2·00 | 1·28 | 2·28 | 1·22 | ·215 | ·10 | ·07 | ·86 |

A = sludge in contact with sewage without intimate mixture.
B = intimate mixture of sewage and sludge.

In each case the samples were settled for 2 hours prior to analysis.

In this experiment a proportion of 1 vol. activated sludge to 25 vols. sewage was employed.

TABLE IA.

*Ratio of Sludge to Sewage.*

| Results in parts of 100,000. | Experiment 91a. | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | | 1 vol. sludge to 9 vols. sewage. | | | | 1 vol. sludge to 6 vols. sewage | | | | 1 vol. sludge to 4 vols. sewage. | | | | 1 vol. sludge to 3 vols. sewage. | | | |
| | Shaken. | Settled. | Original. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Original. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Original. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Original. | 3 Hrs. | 6 Hrs. | 9 Hrs. |
| 4 Hours oxygen absorption (total) | 8·80 | 4·68 | 3·26 | 1·60 | 1·63 | 1·40 | 3·08 | 1·43 | 1·40 | 1·32 | 2·80 | 1·28 | 1·28 | 1·22 | 2·51 | 1·00 | 1·17 | 1·20 |
| Oxidisable matter removed: Crystalloids .. | | 2·57 | 1·72 | ·91 | ·80 | ·80 | 1·63 | ·80 | ·76 | ·76 | 1·37 | ·68 | ·68 | ·68 | 1·31 | ·63 | ·68 | ·66 |
| Oxidisable matter removed: Colloids, etc. | | 2·11 | 1·54 | ·69 | ·83 | ·60 | 1·46 | ·63 | ·64 | ·54 | 1·43 | ·60 | ·60 | ·54 | 1·20 | ·37 | ·49 | ·54 |
| Oxidisable matter removed: Total ..... | | | | 1·66 | 1·63 | 1·86 | | 1·65 | 1·68 | 1·76 | | 1·52 | 1·52 | 1·58 | | 1·51 | 1·34 | 1·31 |
| Oxidisable matter removed: Crystalloids.. | | | | ·81 | ·92 | ·92 | | ·83 | ·87 | ·87 | | ·69 | ·69 | ·69 | | ·68 | ·63 | ·65 |
| Oxidisable matter removed: Colloids, etc. | | | | ·85 | ·71 | ·94 | | ·83 | ·82 | ·92 | | ·83 | ·83 | ·89 | | ·83 | ·71 | ·66 |
| Per cent. reduction on raw sewage | — | 47 | 63 | 82 | 81 | 84 | 65 | 84 | 84 | 85 | 68 | 85 | 85 | 86 | 72 | 89 | 87 | 86 |
| Per cent. reduction on settled sewage | — | — | 30 | 66 | 65 | 70 | 34 | 69 | 70 | 72 | 40 | 73 | 73 | 74 | 46 | 70 | 75 | 74 |
| Free and saline ammonia | 2·57 | 2·57 | 2·28 | 2·07 | 1·86 | 1·50 | 2·14 | 1·93 | 1·64 | 1·14 | 2·00 | 1·71 | 1·28 | ·64 | 1·93 | 1·43 | ·86 | ·37 |
| Reduction in free $NH_3$ | — | — | — | ·21 | ·42 | ·78 | — | ·21 | ·50 | 1·00 | — | ·29 | ·72 | 1·36 | — | ·50 | 1·07 | 1·56 |
| Per cent. reduction on raw sewage | — | — | 11 | 19 | 28 | 42 | 17 | 25 | 36 | 56 | 22 | 33 | 50 | 75 | 25 | 44 | 67 | 86 |
| Albuminoid ammonia .. | ·90 | ·33 | ·315 | ·16 | ·15 | ·12 | ·315 | ·15 | ·12 | ·10 | ·30 | ·13 | ·10 | ·08 | ·26 | ·10 | ·08 | ·005 |
| Reduction in albd. $NH_3$ | | | | ·155 | ·165 | ·195 | | ·165 | ·195 | ·215 | | ·17 | ·20 | ·22 | | ·16 | ·18 | ·195 |
| Per cent. reduction on raw sewage | — | 63 | 65 | 82 | 83 | 87 | 65 | 83 | 87 | 89 | 67 | 86 | 89 | 91 | 74 | 89 | 91 | 93 |
| Per cent. reduction on settled sewage | — | — | 5 | 52 | 55 | 64 | 5 | 55 | 64 | 70 | 9 | 61 | 70 | 76 | 21 | 70 | 76 | 80 |
| Nitrite and nitrate (in terms of $NH_3$) | | | ·06 | ·12 | ·32 | ·43 | ·04 | ·23 | ·54 | ·77 | ·04 | ·36 | ·74 | 1·28 | ·07 | ·47 | ·93 | 1·64 |
| Amount of $NH_3$ oxidised | | | — | ·06 | ·26 | ·37 | — | ·19 | ·50 | ·73 | — | ·32 | ·70 | 1·24 | — | ·40 | ·86 | 1·57 |
| Per cent. of $NH_3$ oxidised | | | 2 | 5 | 12 | 17 | 2 | 9 | 21 | 30 | 2 | 14 | 29 | 50 | 2 | 18 | 36 | 64 |

Except in the case of the original shaken sample, two hours settlement was allowed prior to analysis.

TABLE II.

*Oxidation of Manchester sewage.*

| Results in parts per 100,000. | Experiment 14. | | | | | | Experiment 22. | | | | | | | | Experiment 25. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | R.S.+ sludge. | After aeration in contact with sludge for :— | | | | Raw sewage. | R.S.* | Original settled. | | After aeration for 6 hours | | After aeration for 12 hours. | | Raw sewage. | R.S.* | Original settled. | | After aeration for 6 hours. | | After aeration for 12 hours. | |
| | Shaken. | Settled. | 4 hrs. | 8 hrs. | 12 hrs. | 24 hrs. | Shaken. | Shaken. | R.S.* alone. | R.S+ sludge | R.S.* alone. | R.S+ sludge. | R.S.* alone. | R.S+ sludge | Shaken. | Shaken. | R.S.* alone. | R.S+ sludge. | R.S.* alone. | R.S+ sludge. | R.S.* alone. | R.S+ sludge. |
| 4 hours oxygen absorption | 8·80 | 3·83 | 2·09 | 1·40 | 1·26 | 1·17 | 14·90 | 10·63 | 7·46 | 6·09 | 6·57 | 1·83 | 5·20 | 1·31 | 15·32 | 10·06 | 6·97 | 5·91 | 5·26 | 2·20 | 4·91 | 1·29 |
| Per cent. reduction on raw sewage | — | 56 | 76 | 84 | 86 | 87 | — | 29 | 50 | 59 | 56 | 88 | 65 | 91 | — | 34 | 55 | 61 | 66 | 86 | 68 | 92 |
| Free and saline ammonia | 2·14 | 2·14 | 2·14 | 1·93 | 1·80 | ·96 | 3·43 | 3·00 | 3·00 | 3·00 | 2·57 | 1·31 | 2·14 | nil | 2·43 | 2·29 | 2·29 | 2·29 | 2·29 | 1·14 | 2·14 | nil |
| Per cent. reduction on raw sewage | — | nil | nil | 10 | 16 | 55 | — | 13 | 13 | 13 | 25 | 62 | 38 | 100 | — | 6 | 6 | 6 | 6 | 53 | 12 | 100 |
| Albuminoid ammonia .. | ·73 | ·345 | ·265 | — | ·12 | ·105 | 1·10 | ·82 | ·53 | ·54 | ·415 | ·16 | ·365 | ·135 | 1·07 | ·67 | ·36 | ·36 | ·44 | ·165 | ·305 | ·105 |
| Per cent. reduction on raw sewage | — | 53 | 64 | — | 84 | 86 | — | 25 | 52 | 51 | 62 | 85 | 67 | 88 | — | 37 | 66 | 66 | 59 | 85 | 72 | 90 |
| Nitrite and nitrate (in terms of $NH_3$) | — | ·20 | ·20 | ·32 | ·60 | 1·46 | — | — | nil | ·51 | nil | 1·80 | nil | 2·58 | — | — | — | — | nil | 1·50 | nil | 2·30 |
| Per cent. oxidised ..... | — | 9 | 9 | 15 | 28 | 68 | | | nil | 15 | nil | 52 | nil | 75 | — | — | — | — | nil | 62 | nil | 95 |
| | 1 vol. sludge to 12 vols. sewage. | | | | | | 1 vol. sludge to 4 vols. sewage. | | | | | | | | 1 vol. sludge to 4 vols. sewage. | | | | | | | |

* = Original sewage with 20 per cent. water added, to obviate dilution effect of sludge.

| | Experiment 30. | | | | | Experiment 81. | | | | | Experiment 86. | | | | | Experiment 89. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | Original settled. | | After 6 hrs. aeration. | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | |
| | Shaken. | Alone. | +sludge. | Alone. | +sludge. | Shaken. | Settled. | 3 hrs. | 6 hrs. | 9 hrs. | Shaken. | Settled. | 3 hrs. | 6 hrs. | 9 hrs. | Shaken. | Settled. | 3 hrs. | 6 hrs. | 9 hrs. |
| 4 hours oxygen absorption (total) | 11·20 | 7·29 | 4·57 | 6·63 | 2·09 | 13·37 | 9·40 | 2·00 | 1·37 | 1·20 | 14·27 | 9·30 | 2·97 | 1·34 | 1·12 | 14·63 | 10·10 | 2·17 | 1·50 | 1·29 |
| Crystalloids ..... | | | | | | | | | | | | | | | ·78 | | | 1·14 | ·81 | ·80 |
| Colloids, etc. ..... | | | | | | | | | | | | | | | ·34 | | | 1·03 | ·69 | ·49 |
| Per cent. reduction on raw sewage | — | 35 | 59 | 41 | 81 | — | 30 | 85 | 90 | 91 | — | — | 79 | 91 | 92 | — | 31 | 85 | 90 | 91 |
| Per cent. reduction on settled sewage | — | — | — | — | — | — | — | 79 | 85 | 87 | — | — | 68 | 86 | 88 | — | — | 79 | 85 | 87 |
| Free and saline ammonia | 1·57 | 1·57 | 1·29 | 1·57 | nil | 3·71 | 3·71 | 2·80 | 2·00 | 1·14 | 3·30 | 3·30 | 2·86 | 2·14 | 1·36 | 4·14 | 4·14 | 3·43 | 2·00 | 1·43 |
| Per cent. reduction on raw sewage | | nil | 18 | nil | 100 | — | — | 25 | 46 | 72 | — | — | 13 | 35 | 59 | — | — | 17 | 52 | 65 |
| Albuminoid ammonia .. | ·50 | ·385 | ·385 | ·385 | ·15 | 1·36 | ·70 | ·18 | ·105 | ·08 | 1·10 | ·62 | ·205 | ·10 | ·08 | 1·43 | 1·04 | ·22 | ·115 | ·105 |
| Per cent. reduction on raw sewage | | 23 | 23 | 23 | 70 | — | 49 | 87 | 92 | 94 | — | 48 | 83 | 92 | 93 | — | 27 | 85 | 92 | 93 |
| Per cent. reduction on settled sewage | | — | — | — | — | — | — | 74 | 85 | 89 | — | — | 69 | 84 | 87 | — | — | 79 | 89 | 90 |
| Nitrite and nitrate (in terms of $NH_3$) | | nil | ·07 | nil | 1·70 | — | — | ·10 | ·52 | ·92 | — | — | ·04 | ·34 | ·80 | — | — | ·04 | ·80 | 1·14 |
| Per cent. oxidised ..... | | nil | 4 | nil | 100+ | — | — | 3 | 14 | 25 | — | — | 1 | 10 | 24 | — | — | 1 | 10 | 28 |
| | 1 vol. sludge to 3 vols. sewage. | | | | | 1 vol. sludge to 4 vols. sewage. | | | | | 1 vol. sludge to 4 vols. sewage. | | | | | 1 vol. sludge to 4 vols. sewage. | | | | |

TABLE III.

*Results of sectionised experiments.*

| Results in parts per 100,000. | Experiment 40. | | | | | Experiment 41. | | | | | Experiment 45. | | | | | Experiment 47. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | | Effluent after aeration in contact with | | | Raw sewage. | | Effluent after aeration in contact with | | | Raw sewage. | | Effluent after aeration in contact with | | | Raw sewage. | | Effluent after aeration in contact with | | |
| | Shaken. | Settled. | α sludge. | β sludge. | αβ sludge. | Shaken. | Settled. | α sludge. | β sludge. | αβ sludge. | Shaken. | Settled. | α sludge | β sludge. | αβ sludge. | Shaken. | Settled. | α sludge. | β sludge. | αβ sludge. |
| 4 hours oxygen absorption .... | 12·68 | 8·92 | 3·26 | 2·28 | 2·34 | 9·70 | 6·63 | 2·86 | 2·06 | 2·00 | 10·06 | 7·90 | 3·48 | 2·70 | 2·09 | 17·14 | 13·00 | 6·00 | 3·28 | 2·94 |
| Per cent. reduction Raw sewage | | | 74 | 82 | 81 | | | 71 | 80 | 80 | | | 65 | 75 | 80 | | | 65 | 81 | 83 |
| calculated on Settled sewage | | | 63 | 74 | 73 | | | 57 | 69 | 70 | | | 56 | 66 | 74 | | | 54 | 75 | 77 |
| Free and saline ammonia..... | 3·86 | | | 3·86 | 3·86 | 3·00 | | | 3·28 | 3·28 | 3·70 | | | 3·28 | 2·86 | 4·28 | | | 4·14 | 3·43 |
| Per cent. reduction calculated on raw sewage | | | | nil | nil | | | | nil | nil | | | | 11 | 23 | | | | 3 | 20 |
| Albuminoid ammonia ..... | 1·70 | 1·04 | | ·36 | ·36 | 1·10 | ·50 | | ·25 | ·245 | 1.10 | ·70 | | ·405 | ·35 | 1·61 | 1·02 | | ·405 | ·45 |
| Per cent. reduction Raw sewage.. | | | | 79 | 79 | | | | 77 | 78 | | | | 63 | 68 | | | | 75 | 72 |
| calculated on Settled sewage | | | | 65 | 65 | | | | 50 | 51 | | | | 42 | 50 | | | | 60 | 56 |
| Nitrite and nitrate (in terms of $NH_3$) | | | | ·12 | .36 | | | | ·11 | ·17 | | | | ·12 | ·16 | | | | ·04 | ·06 |
| Per cent. of ammonia oxidised .. | | | | 3 | 9 | | | | 4 | 6 | | | | 3 | 4 | | | | 1 | 1 |
| Temperature | | | | | | | | 6·2°C. | | | 5·5° C. | | | 7·5°C. | 7·5°C | 9·0° C. | | | | |

α Sludge = Partially activated sludge—non-nitrifying.
β and αβ Sludge = Thoroughly activated sludge—capable of vigorously promoting nitrification.

TABLE IV.

*Oxidation of Manchester Sewage under Various Conditions.*

A = 1 Filling with 20 hours aeration.
B = 2 Fillings with 10 hours aeration each
C = 1 Filling with 6 hours aeration with subsequent aeration of sludge alone
D = 3 Fillings with 6 hours aeration each.

FIRST WEEK.

| Results in parts per 100,000 | Experiment 54. | | | | | | Experiment 55. | | | | | | Experiment 56. | | | | | | Experiment 57. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original. | | After 6 hours aeration. | | | | Original. | | After 6 hours aeration. | | | | Original. | | After 6 hours aeration. | | | | Original. | | After 6 hours aeration. | | | |
| | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. |
| 4 Hours oxygen absorption .... | 15·90 | 9 30 | 1·71 | 1·77 | 1·91 | 1·69 | 14·74 | 9·60 | 1·86 | 2·09 | 2·57 | 2·00 | 13·60 | 10·50 | 1·66 | 1·83 | 2·28 | 2·09 | 16·80 | 9·90 | 1·48 | 1·52 | 1·86 | 2·00 |
| Per cent. reduction Raw sewage.. | | | 89 | 89 | 88 | 89 | | | 87 | 86 | 83 | 86 | | | 88 | 87 | 83 | 85 | | | 91 | 91 | 89 | 88 |
| calculated on Settled sewage | | | 82 | 81 | 79 | 82 | | | 81 | 78 | 73 | 79 | | | 84 | 82 | 78 | 80 | | | 85 | 85 | 81 | 80 |
| Free and saline ammonia..... | 4·00 | — | 2·86 | 2·86 | 2·86 | 2·70 | 3·60 | — | 2·57 | 3·43 | 3·30 | 3·15 | 3·50 | — | 1·30 | 2·30 | 2·36 | 2·30 | 3·30 | — | 1·57 | 2·43 | 2·00 | 2·57 |
| Per cent. reduction calculated on raw sewage | | | 38 | 38 | 38 | 41 | | | 29 | 5 | 8 | 12 | | | 65 | 37 | 36 | 37 | | | 52 | 26 | 39 | 22 |
| Albuminoid ammonia ..... | 1·19 | ·73 | ·25 | ·26 | ·265 | ·25 | 1·04 | ·73 | ·22 | ·22 | ·305 | ·205 | ·84 | ·50 | ·28 | ·205 | 205 | ·35 | ·87 | ·47 | ·135 | ·135 | ·15 | ·18 |
| Per cent. reduction Raw sewage.. | | | 79 | 78 | 78 | 79 | | | 79 | 79 | 71 | 80 | | | 67 | 76 | 76 | 58 | | | 84 | 84 | 83 | 79 |
| Calculated on Settled sewage | | | 66 | 64 | 64 | 66 | | | 70 | 70 | 58 | 72 | | | 44 | 59 | 59 | 30 | | | 71 | 71 | 68 | 62 |
| Nitrite and nitrate (in terms of $NH_3$) | — | — | ·91 | ·91 | ·86 | 1·00 | — | — | ·86 | ·06 | ·14 | ·06 | — | — | 1·02 | 12 | ·12 | nil | — | — | ·71 | ·17 | ·20 | ·07 |
| Per cent. of ammonia oxidised .. | | | 20 | 20 | 19 | 22 | | | 24 | 2 | 4 | 2 | | | 29 | 3 | 3 | nil | | | 22 | 3 | 6 | 2 |

| | Second Week. | | | | | | | | | | | | Third Week. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Experiment 59. | | | | | | Experiment 62. | | | | | | Experiment 65. | | | | | | Experiment 66. | | | | | |
| | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. | Shkn. | Sttld. | A. | B. | C. | D. |
| 4 Hours oxygen absorption total | 15·20 | 10·50 | 2·09 | 1·92 | 2·03 | 2·26 | 16·68 | 11·00 | 1·46 | 2·20 | 1·52 | 3·37 | 14·86 | 10·00 | 1·74 | 2·03 | 1·71 | 2·57 | 15·66 | 11·20 | 1·46 | 1·74 | 1·51 | 2·74 |
| Crystalloids | | 6·57 | 1·00 | 1·06 | ·94 | 1·34 | | 6·63 | — | — | — | — | | 5·37 | 1·09 | 1·12 | 1·11 | 1·31 | | 6·52 | 1·06 | 1·03 | ·97 | 1·71 |
| Colloids, &c. | | 3·93 | 1·09 | ·86 | 1·09 | ·92 | | 4·37 | — | — | — | — | | 4·63 | ·66 | ·91 | ·60 | 1·26 | | 4·68 | ·40 | ·71 | ·54 | 1·03 |
| Per cent. reduction calculated on Raw sewage | | | 86 | 87 | 87 | 85 | | | 91 | 87 | 91 | 80 | | | 88 | 86 | 89 | 83 | | | 91 | 89 | 90 | 83 |
| Per cent. reduction calculated on Settled sewage | | | 80 | 82 | 81 | 79 | | | 87 | 80 | 86 | 69 | | | 83 | 80 | 83 | 74 | | | 87 | 84 | 87 | 76 |
| Free and saline ammonia | 3·57 | — | 2·14 | 2·72 | 2·14 | 2·86 | 3·86 | | 2·14 | 3·70 | 2·28 | 4·14 | 3·93 | | 2·43 | 3·14 | 2·00 | 3·43 | 3·60 | | 1·70 | 2·30 | 1·70 | 3·15 |
| Per cent. reduction calculated on raw sewage | | | 40 | 24 | 40 | 20 | | | 45 | 4 | 41 | — | | | 38 | 20 | 49 | 13 | | | 53 | 36 | 53 | 13 |
| Albuminoid ammonia | 1·16 | ·62 | ·18 | ·18 | ·18 | ·205 | 1·27 | ·79 | ·205 | ·205 | ·18 | ·39 | 1·10 | ·53 | ·165 | ·22 | ·15 | ·28 | 1·58 | ·62 | ·165 | ·165 | ·105 | ·25 |
| Per cent. reduction calculated on Raw sewage | | | 84 | 84 | 84 | 82 | | | 84 | 79 | 86 | 69 | | | 85 | 80 | 86 | 75 | | | 93 | 90 | 93 | 84 |
| Per cent. reduction calculated on Settled sewage | | | 71 | 71 | 71 | 68 | | | 74 | 67 | 77 | 57 | | | 69 | 58 | 72 | 47 | | | 83 | 73 | 83 | 60 |
| Nitrite and nitrate (in terms of $NH_3$) | | | ·96 | ·38 | ·60 | ·09 | | | ·17 | ·03 | ·22 | ·04 | | | ·20 | nil | ·19 | nil | | | ·36 | ·03 | ·33 | nil |
| Per cent. of ammonia oxidised | | | 27 | 11 | 17 | 3 | | | 4 | 1 | 6 | 1 | | | 5 | nil | 5 | nil | | | 10 | 1 | 9 | nil |

## Table V.

*Effect of Temperature.*

| Results in parts per 100,000. | Temp. | Experiment 93. | | | | | Experiment 94. | | | | | Experiment 95. | | | | | Experiment 96. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | |
| | | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. |
| 4 Hours oxygen absorption Total | 5° C. | 10·63 | 7·70 | 2·23 | 1·88 | 1·60 | 15·31 | 9·00 | 3·03 | 2·74 | 2·69 | 13·94 | 7·80 | 3·09 | 2·72 | 2·83 | 11·80 | 8·50 | 2·80 | 2·63 | 2·28 |
| Crystalloids | 5° C. | | 5·26 | 1·16 | ·91 | ·88 | | 5·09 | 1·44 | 1·26 | 1·17 | | 4·34 | 1·32 | 1·06 | 1·04 | | 4·80 | 1·23 | 1·09 | 1·00 |
| Colloids, etc. | 5° C. | | 2·44 | 1·07 | ·97 | ·72 | | 3·91 | 1·59 | 1·48 | 1·52 | | 3·46 | 1·77 | 1·66 | 1·79 | | 3·70 | 1·57 | 1·54 | 1·28 |
| Total | 15° C. | | | 1·57 | 1·37 | 1·29 | | | 2·29 | 1·48 | 1·49 | | | 1·97 | 1·40 | 1·17 | | | 1·77 | 1·37 | 1·17 |
| Crystalloids | 15° C. | | | ·88 | ·83 | ·83 | | | 1·26 | ·94 | ·96 | | | 1·16 | ·83 | ·77 | | | 1·16 | ·81 | ·71 |
| Colloids, etc. | 15° C. | | | ·69 | ·54 | ·46 | | | 1·03 | ·54 | ·53 | | | ·81 | ·57 | ·40 | | | ·61 | ·56 | ·46 |
| Per cent. reduction calculated on Raw sewage | 5° C. | | | 79 | 82 | 85 | | | 80 | 82 | 82 | | | 78 | 81 | 80 | | | 76 | 78 | 81 |
| Per cent. reduction calculated on Raw sewage | 15° C. | | | 85 | 87 | 88 | | | 85 | 90 | 90 | | | 86 | 90 | 92 | | | 85 | 88 | 90 |
| Per cent. reduction calculated on Settled sewage | 5° C. | | | 71 | 76 | 79 | | | 66 | 70 | 70 | | | 60 | 65 | 64 | | | 67 | 69 | 73 |
| Per cent. reduction calculated on Settled sewage | 15° C. | | | 80 | 82 | 83 | | | 75 | 84 | 84 | | | 75 | 82 | 85 | | | 79 | 84 | 86 |
| Colloids, etc., removed | 5° C. | | | 1·37 | 1·47 | 1·72 | | | 2·32 | 2·43 | 2·39 | | | 1·69 | 1·80 | 1·67 | | | 2·13 | 2·16 | 2·42 |
| | 15° C. | | | 1·75 | 1·90 | 1·98 | | | 2·88 | 3·37 | 3·38 | | | 2·65 | 2·89 | 3·06 | | | 3·09 | 3·14 | 3·24 |
| Free and Saline ammonia | 5° C. | 4·43 | 4·43 | 4·43 | 4·00 | 3·71 | 3·86 | 3·86 | 3·57 | 3·36 | 3·29 | 2·50 | 2·50 | 2·64 | 2·36 | 2·21 | 3·28 | 3·28 | 2·64 | 2·64 | 2·43 |
| | 15° C. | | | 3·80 | 3·07 | 2·43 | | | 3·07 | 2·28 | 1·36 | | | 1·93 | 1·12 | ·23 | | | 2·43 | 2·07 | 1·14 |
| Per cent. reduction | 5° C. | | | nil | 10 | 16 | | | 7 | 13 | 15 | | | nil | 5 | 12 | | | 20 | 20 | 26 |
| | 15° C. | | | 14 | 30 | 45 | | | 20 | 41 | 65 | | | 23 | 55 | 91 | | | 26 | 37 | 65 |
| Albuminoid ammonia | 5° C. | ·98 | ·54 | ·27 | 215 | ·165 | 1·16 | ·62 | ·335 | ·37 | ·42 | 1·30 | ·56 | ·40 | ·35 | ·35 | ·98 | ·46 | ·28 | ·305 | ·27 |
| | 15° C. | | | ·165 | ·13 | ·065 | | | ·23 | ·205 | ·165 | | | ·215 | ·15 | ·08 | | | ·15 | ·17 | ·115 |
| Per cent. reduction calculated on Raw sewage | 5° C. | | | 72 | 78 | 83 | | | 71 | 68 | 64 | | | 69 | 73 | 73 | | | 71 | 69 | 72 |
| Per cent. reduction calculated on Raw sewage | 15° C. | | | 83 | 87 | 93 | | | 80 | 82 | 86 | | | 83 | 88 | 94 | | | 85 | 83 | 88 |
| Per cent. reduction calculated on Settled sewage | 5° C. | | | 50 | 60 | 69 | | | 46 | 40 | 32 | | | 28 | 37 | 37 | | | 39 | 34 | 41 |
| Per cent. reduction calculated on Settled sewage | 15° C. | | | 69 | 76 | 88 | | | 63 | 67 | 73 | | | 62 | 73 | 86 | | | 67 | 63 | 75 |
| Nitrite and nitrate (in terms of $NH_3$) | 5° C. | | | ·07 | ·17 | ·26 | | | ·04 | ·06 | ·06 | | | ·03 | ·04 | ·14 | | | ·14 | ·07 | ·12 |
| | 15° C. | | | ·07 | ·54 | ·97 | | | ·04 | ·40 | ·86 | | | ·10 | ·60 | 1·14 | | | ·04 | ·27 | ·54 |
| Per cent. of ammonia oxidised | 5° C. | | | 2 | 4 | 6 | | | 1 | 2 | 2 | | | 1 | 2 | 6 | | | 4 | 2 | 4 |
| | 15° C. | | | 2 | 12 | 22 | | | 1 | 10 | 22 | | | 4 | 24 | 46 | | | 1 | 8 | 16 |

TABLE VI.

*Effect of Temperature.*

| Results in parts per 100,000 | Temp. | Experiment 73. | | | | | Experiment 74. | | | | | Experiment 75. | | | | | Experiment 76. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | |
| | | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. |
| 4 Hours oxygen absorption | 13° C. | 12·11 | 8·30 | | 1·46 | | 10·50 | 6·40 | 1·26 | 1·26 | ·91 | 10·30 | 7·40 | 1·51 | 1·31 | 1·09 | 12·10 | 8·80 | 1·66 | 1·37 | 1·37 |
| | 20° C. | | | | 1·49 | | | | 1·23 | 1·29 | ·91 | | | 1·63 | 1·31 | 1·03 | | | 1·63 | 1·31 | 1·40 |
| | 30° C. | | | | 2·20 | | | | 2·03 | 1·97 | 1·51 | | | 1·91 | 1·49 | 1·89 | | | 2·11 | 1·71 | — |
| Per cent. reduction calculated on: Raw sewage | 13° C. | | | | 88 | | | | 88 | 88 | 91 | | | 85 | 87 | 89 | | | 86 | 89 | 89 |
| Per cent. reduction calculated on: Raw sewage, Do. | 20° C. | | | | 88 | | | | 88 | 88 | 91 | | | 84 | 87 | 90 | | | 87 | 89 | 88 |
| Per cent. reduction calculated on: Raw sewage, Do. | 30° C. | | | | 82 | | | | 81 | 81 | 86 | | | 81 | 86 | 82 | | | 83 | 86 | 80 |
| Per cent. reduction calculated on: Settled sewage | 13° C. | | | | 82 | | | | 80 | 80 | 86 | | | 80 | 82 | 85 | | | 81 | 84 | 84 |
| Per cent. reduction calculated on: Settled sewage, Do. | 20° C. | | | | 82 | | | | 81 | 80 | 86 | | | 78 | 82 | 86 | | | 82 | 85 | 84 |
| Per cent. reduction calculated on: Settled sewage, Do. | 30° C | | | | 74 | | | | 68 | 69 | 76 | | | 74 | 80 | 75 | | | 76 | 81 | .. |
| Free and saline ammonia | 13° C. | 3·80 | | | 2·14 | | 2·14 | | 1·43 | ·71 | nil | 2·56 | | 2·14 | 1·43 | ·54 | 2·56 | | 2·14 | 1·64 | ·79 |
| | 20° C. | | | | 2·43 | | | | 1·29 | ·23 | nil | | | 2·14 | 1·29 | ·20 | | | 2·21 | 1·57 | ·36 |
| | 30° C. | | | | 2·57 | | | | 1·57 | ·57 | nil | | | 2·36 | 1·71 | ·29 | | | 2·29 | 1·93 | ·60 |
| Per cent. reduction calculated on raw sewage | 13° C. | | | | 41 | | | | 33 | 67 | 100 | | | 16 | 44 | 79 | | | 16 | 36 | 69 |
| | 20° C. | | | | 36 | | | | 40 | 89 | 100 | | | 16 | 50 | 92 | | | 14 | 39 | 86 |
| | 30° C. | | | | 32 | | | | 27 | 73 | 100 | | | 8 | 33 | 89 | | | 11 | 25 | 77 |
| Albuminoid ammonia | 13° C. | ·96 | ·61 | | ·105 | | ·84 | ·36 | ·13 | ·10 | ·08 | ·70 | ·44 | ·165 | ·13 | ·095 | ·96 | ·64 | ·16 | ·105 | ·08 |
| | 20° C. | | | | ·105 | | | | ·10 | ·10 | ·08 | | | ·18 | ·115 | ·095 | | | ·15 | ·105 | ·08 |
| | 30° C. | | | | ·265 | | | | ·22 | ·165 | ·11 | | | ·20 | ·165 | ·105 | | | ·20 | ·15 | ·12 |
| Per cent. reduction calculated on: Raw sewage | 13° C. | | | | 89 | | | | 85 | 88 | 90 | | | 76 | 81 | 86 | | | 83 | 89 | 92 |
| Per cent. reduction calculated on: Raw sewage, Do. | 20° C. | | | | 89 | | | | 88 | 88 | 90 | | | 74 | 84 | 86 | | | 84 | 89 | 92 |
| Per cent. reduction calculated on: Raw sewage, Do. | 30° C | | | | 72 | | | | 74 | 80 | 87 | | | 71 | 76 | 85 | | | 79 | 84 | 88 |
| Per cent. reduction calculated on: Settled sewage | 13° C | | | | 83 | | | | 64 | 72 | 78 | | | 63 | 70 | 78 | | | 75 | 84 | 88 |
| Per cent. reduction calculated on: Settled sewage, Do. | 20° C | | | | 83 | | | | 72 | 72 | 78 | | | 59 | 74 | 78 | | | 77 | 84 | 88 |
| Per cent. reduction calculated on: Settled sewage, Do. | 30° C. | | | | 57 | | | | 30 | 54 | 69 | | | 55 | 63 | 76 | | | 69 | 77 | 81 |
| Nitrite and nitrate (in terms of $NH_3$) | 13° C. | | | | ·63 | | | | ·10 | ·44 | 1·34 | | | ·11 | ·81 | 1·19 | | | ·10 | ·50 | 1·21 |
| | 20° C. | | | | ·21 | | | | ·17 | ·76 | 1·31 | | | ·09 | 56 | 1·43 | | | nil | ·57 | 1·64 |
| | 30° C. | | | | ·06 | | | | ·09 | ·60 | 1·17 | | | ·03 | ·31 | 1·24 | | | ·03 | ·21 | 1·00 |
| Per cent. of ammonia oxidised | 13° C. | | | | 17 | | | | 5 | 21 | 63 | | | 4 | 32 | 46 | | | 4 | 19 | 47 |
| | 20° C. | | | | 6 | | | | 8 | 32 | 61 | | | 3 | 20 | 56 | | | nil | 20 | 64 |
| | 30° C. | | | | 2 | | | | 4 | 28 | 55 | | | 1 | 12 | 48 | | | 1 | 8 | 39 |

TABLE VII.

*Effect of Temperature.*

| Results in parts per 100,000. | Temp. | Experiment 70. | | | | | Experiment 80. | | | | | Experiment 81. | | | | | Experiment 82. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | | Raw sewage. | | After aeration for | | |
| | | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. | Shaken. | Settled. | 3 Hrs. | 6 Hrs. | 9 Hrs. |
| 4 Hours oxygen absorption | 13° C. | 11·66 | 8·30 | 1·80 | 1·09 | 1·03 | 11·77 | 8·40 | 2·20 | 1·43 | 1·20 | 13·37 | 9·40 | 2·00 | 1·37 | 1·20 | 13·60 | 8·80 | 1·77 | 1·31 | 1·29 |
| | 20° C. | | | 2·17 | 1·28 | 1·11 | | | 1·97 | 1·54 | 1·26 | | | 2·37 | 1·57 | 1·34 | | | 2·06 | 1·43 | 1·12 |
| | 30° C. | | | 3·26 | 2·06 | 1·43 | | | 2·60 | 1·77 | 1·40 | | | 3·26 | 2·06 | 1·71 | | | 2·51 | 1·69 | 1·66 |
| Per cent. reduction calculated on — Raw sewage | 13° C. | | | 85 | 91 | 91 | | | 81 | 88 | 90 | | | 85 | 90 | 91 | | | 87 | 90 | 90 |
| Do. | 20° C. | | | 81 | 89 | 90 | | | 84 | 87 | 89 | | | 82 | 88 | 90 | | | 85 | 89 | 92 |
| Do. | 30° C. | | | 72 | 82 | 88 | | | 78 | 85 | 88 | | | 76 | 85 | 87 | | | 82 | 88 | 88 |
| Settled sewage | 13° C. | | | 78 | 87 | 88 | | | 74 | 83 | 86 | | | 70 | 85 | 87 | | | 80 | 85 | 85 |
| Do. | 20° C. | | | 74 | 85 | 87 | | | 77 | 82 | 85 | | | 75 | 83 | 86 | | | 77 | 84 | 87 |
| Do. | 30° C. | | | 61 | 75 | 83 | | | 69 | 70 | 83 | | | 65 | 78 | 82 | | | 72 | 81 | 81 |
| Free and saline ammonia | 13° C. | 2·86 | 2·86 | 1·93 | 1·14 | ·30 | 3·20 | 3·20 | 2·57 | 1·93 | 1·57 | 3·70 | 3·70 | 2·80 | 2·00 | 1·13 | 3·70 | 3·70 | 2·57 | 1·71 | 1·14 |
| | 20° C. | | | 2·00 | ·93 | nil | | | 2·36 | 1·20 | nil | | | 2·93 | 2·21 | 1·00 | | | 2·64 | 1·64 | ·64 |
| | 30° C. | | | 2·43 | 1·64 | ·53 | | | 2·57 | 1·93 | ·80 | | | 3·07 | 2·86 | 1·50 | | | 2·80 | 2·22 | ·60 |
| Per cent. reduction calculated on raw sewage | 13° C. | | | 33 | 60 | 86 | | | 20 | 40 | 51 | | | 24 | 46 | 69 | | | 31 | 54 | 69 |
| | 20° C. | | | 30 | 67 | 100 | | | 26 | 60 | 100 | | | 21 | 40 | 73 | | | 29 | 56 | 83 |
| | 30° C. | | | 15 | 42 | 82 | | | 20 | 40 | 75 | | | 17 | 23 | 59 | | | 24 | 40 | 84 |
| Albuminoid ammonia .. | 13° C. | ·84 | ·50 | ·205 | ·095 | ·065 | ·98 | ·50 | ·215 | ·12 | ·10 | 1·36 | ·70 | ·18 | ·105 | ·08 | ·98 | ·62 | ·165 | ·105 | ·085 |
| | 20° C. | | | ·23 | ·105 | ·07 | | | ·205 | ·13 | ·10 | | | ·22 | ·13 | ·08 | | | ·195 | ·105 | ·085 |
| | 30° C. | | | ·45 | ·22 | ·12 | | | ·23 | ·165 | ·12 | | | ·405 | ·25 | ·18 | | | ·23 | ·12 | ·085 |
| Per cent. reduction calculated on — Raw sewage | 13° C. | | | 76 | 89 | 92 | | | 78 | 88 | 90 | | | 87 | 92 | 94 | | | 73 | 89 | 91 |
| Do. | 20° C. | | | 73 | 87 | 92 | | | 79 | 87 | 90 | | | 84 | 91 | 94 | | | 80 | 89 | 91 |
| Do. | 30° C. | | | 46 | 74 | 86 | | | 77 | 73 | 88 | | | 70 | 82 | 87 | | | 77 | 88 | 91 |
| Settled sewage | 13° C. | | | 59 | 81 | 87 | | | 57 | 76 | 80 | | | 74 | 85 | 89 | | | 73 | 83 | 86 |
| Do. | 20° C. | | | 54 | 79 | 86 | | | 59 | 74 | 80 | | | 69 | 81 | 89 | | | 69 | 83 | 86 |
| Do. | 30° C. | | | 10 | 56 | 76 | | | 54 | 67 | 76 | | | 42 | 64 | 74 | | | 63 | 81 | 86 |
| Nitrite and nitrate (in terms of $NH_3$) .... | 13° C. | | | ·06 | 1·14 | 1·79 | | | ·06 | ·43 | ·69 | | | ·10 | ·51 | ·92 | | | ·10 | ·31 | 1·20 |
| | 20° C. | | | ·03 | 1·14 | 1·83 | | | ·04 | ·69 | 1·83 | | | nil | ·28 | 1·06 | | | nil | ·46 | 1·48 |
| | 30° C. | | | nil | ·57 | 1·14 | | | ·03 | ·31 | ·83 | | | nil | ·20 | ·52 | | | nil | ·20 | 1·20 |
| Per cent. of ammonia oxidised ..... | 13° C. | | | 2 | 40 | 63 | | | 2 | 14 | 22 | | | 3 | 14 | 25 | | | 3 | 8 | 32 |
| | 20° C. | | | 1 | 40 | 64 | | | 1 | 22 | 57 | | | nil | 8 | 29 | | | nil | 12 | 40 |
| | 30° C. | | | 0 | 20 | 40 | | | 1 | 10 | 26 | | | nil | 5 | 14 | | | nil | 5 | 32 |

TABLE VIII.

*Oxidation of Various Sewages.*

*Moss Side Sewage.*

| Results in parts per 100,000. | Sample A. | | | | | | | | | | | Sample B. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original. | | | After aeration for | | | | | | | | Original. | | | After aeration for | | | | | | | |
| | Shaken. | After 2 hrs. settlement. | | 3 Hours. | | 6 Hours. | | 12 Hours. | | 24 Hours. | | Shaken. | After 2 hrs. settlement. | | 3 Hours. | | 6 Hours. | | 12 Hours. | | 24 Hours. | |
| | | Alone. | + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. | | Alone. | + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. | Sewage. | Sewage + sludge. |
| 4 Hours oxygen absorption (total) .. | 9·83 | 8·57 | 10·88 | 8·71 | 5·55 | 8·88 | 4·00 | 5·76 | 2·16 | 3·60 | 1·49 | 11·66 | 9·00 | 8·10 | 8·50 | 2·74 | 7·60 | 2·34 | 4·16 | 1·54 | 3·43 | 1·51 |
| Crystalloids ..... | | 4·00 | 3·88 | 3·68 | 1·62 | 3·54 | 1·26 | 2·00 | ·96 | — | — | | 4·23 | 3·80 | 2·86 | 1·57 | 2·97 | 1·11 | — | — | — | — |
| Colloids, &c. ..... | | 4·51 | 7·00 | 5·03 | 3·93 | 5·34 | 2·74 | 3·76 | 1·20 | — | — | | 4·77 | 4·21 | 5·64 | 1·17 | 4·63 | 1·23 | — | — | — | — |
| Per cent. reduction Shaken sample | | 13 | nil | 10 | 43 | 8 | 59 | 41 | 78 | 63 | 85 | | 23 | 30 | 27 | 77 | 35 | 80 | 64 | 87 | 71 | 87 |
| calculated on Settled sample | | — | nil | nil | 35 | nil | 53 | 33 | 75 | 58 | 83 | | — | 10 | 6 | 70 | 16 | 74 | 54 | 83 | 62 | 83 |
| Free and saline ammonia..... | 6·00 | 6·00 | 6·14 | 6·07 | 5·43 | 5·71 | 4·43 | 5·14 | 3·28 | 3·57 | 1·14 | 6·00 | 6·00 | 6·00 | 5·57 | 4·29 | 5·14 | 3·29 | 3·43 | 1·21 | 2·86 | nil |
| Per cent. reduction ..... | | — | nil | nil | 10 | 5 | 26 | 14 | 45 | 40 | 81 | | — | nil | 7 | 29 | 14 | 45 | 43 | 80 | 52 | 100 |
| Albuminoid ammonia ..... | 1·19 | ·96 | 1·36 | ·90 | ·67 | ·83 | ·33 | ·74 | ·29 | ·585 | ·15 | 2·20 | 1·27 | 1·26 | 1·09 | ·40 | ·83 | ·22 | ·79 | ·16 | ·63 | ·10 |
| Per cent. reduction Shaken sample | | 19 | nil | 24 | 44 | 30 | 72 | 38 | 76 | 51 | 87 | | 42 | 43 | 50 | 82 | 62 | 90 | 64 | 93 | 71 | 95 |
| calculated on Settled sample | | — | nil | 6 | 30 | 13 | 66 | 23 | 70 | 39 | 84 | | —. | 1 | 14 | 69 | 35 | 83 | 38 | 89 | 50 | 92 |
| Nitrite and nitrate (in terms of $NH_3$) | | nil | ·12 | nil | ·42 | nil | ·98 | nil | 1·43 | nil | 3·92 | | nil | ·07 | nil | ·50 | nil | 1·14 | nil | 2·57 | nil | 3·50 |
| Per cent. of ammonia oxidised ..... | | nil | 2 | nil | 7 | nil | 16 | nil | 24 | nil | 65 | | nil | 1 | nil | 8 | nil | 19 | nil | 43 | nil | 58 |

*Withington Sewage.*

| | Original. | | After aeration for | | | | | | | | Original. | | After aeration for | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | | 2 Hours. | | 4 Hours. | | 6 Hours. | | 9 Hours. | | Raw sewage. | | 3 Hours. | | 6 Hours. | | 7 Hours. | |
| | Shaken. | Settled. | Alone. | + sludge. | Alone. | + sludge | Alone. | + sludge. | Alone. | + sludge. | Shaken. | Settled. | Alone. | + sludge. | Alone. | + sludge. | Alone. | + sludge. |
| 4 Hours oxygen absorption Total ..... | 5·12 | 3·77 | 2·86 | 1·28 | 2·17 | 1·03 | 2·06 | 1·00 | 1·71 | 1·00 | 5·60 | 2·92 | 2·29 | 1·53 | 1·88 | 1·20 | 1·88 | 1·26 |
| Crystalloids .... | | 1·49 | 1·17 | ·54 | ·88 | ·56 | ·94 | ·51 | | | | | — | — | — | — | ·91 | ·69 |
| Colloids, &c. .. | | 2·28 | 1·69 | ·74 | 1·29 | ·47 | 1·12 | ·49 | | | | | — | — | — | — | ·97 | ·57 |
| Per cent. reduction Shaken sample | | 26 | 44 | 75 | 58 | 80 | 60 | 80 | 67 | 80 | — | 48 | 59 | 73 | 67 | 79 | 67 | 78 |
| calculated on Settled sample | | — | 24 | 66 | 42 | 73 | 45 | 74 | 55 | 74 | — | — | 22 | 48 | 36 | 59 | 36 | 57 |
| Free and saline ammonia..... | 2·78 | 2·78 | 2·28 | 1·80 | 2·14 | 1·07 | 2·14 | ·64 | 2·21 | ·09 | 2·29 | 1·86 | 1·36 | 1·29 | 1·40 | ·26 | 1·36 | nil |
| Per cent. reduction ..... | — | — | 18 | 35 | 23 | 62 | 23 | 77 | 21 | 97 | — | 19 | 41 | 44 | 39 | 89 | 41 | 100 |
| Albuminoid ammonia ..... | ·815 | ·50 | ·405 | ·15 | ·405 | ·08 | ·38 | ·08 | ·42 | ·07 | ·70 | ·30 | ·285 | ·15 | ·23 | ·06 | ·15 | ·05 |
| Per cent. reduction Shaken sample | — | 39 | 50 | 82 | 50 | 90 | 53 | 90 | 48 | 91 | — | 57 | 59 | 79 | 67 | 91 | 79 | 93 |
| calculated on Settled sample | — | — | 19 | 70 | 19 | 84 | 24 | 84 | 16 | 86 | — | — | 5 | 50 | 23 | 80 | 50 | 83 |
| Nitrite and nitrate (in terms of $NH_3$) | | | ·23 | ·50 | ·215 | 1·31 | ·06 | 1·50 | ·09 | 1·72 | | | nil | ·46 | nil | 1·09 | nil | 1·37 |
| Per cent. of ammonia oxidised ..... | | | 8 | 18 | 8 | 47 | 2 | 54 | 3 | 62 | | | nil | 20 | nil | 48 | nil | 60 |

## Table IX.

*Oxidation of Various Sewages.*

| Results in parts per 100,000 | Gorton. | | | | | | Macclesfield. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw sewage. | | After aeration for | | | | Raw sewage. | | After aeration for | | | | | |
| | | | 3 Hours. | | 9 Hours, | | | | 3 Hours. | | 6 Hours. | | 9 Hours. | |
| | Shaken. | Settled. | Alone. | + sludge. | Alone. | + sludge. | Shaken. | Settled. | Alone. | + sludge. | Alone. | + sludge. | Alone. | + sludge. |
| 4 Hours Oxygen absorption — Total | 15·43 | 11·70 | 9·49 | 2·57 | 6·86 | 1·28 | 12·57 | 9·10 | 8·50 | 2·72 | 7·30 | 1·66 | 6·50 | 1·37 |
| Crystalloids | | 6·28 | 4·57 | 1·54 | 2·52 | ·80 | | 4·06 | 3·66 | 1·12 | 2·51 | ·80 | 2·46 | ·74 |
| Colloids, etc. | | 5·42 | 4·92 | 1·03 | 4·34 | ·48 | | 5·04 | 4·84 | 1·60 | 4·79 | ·86 | 4·04 | ·63 |
| Per cent. reduction calculated on — Raw sewage | | 24 | 38 | 83 | 55 | 92 | | 27 | 32 | 78 | 42 | 87 | 48 | 89 |
| Settled sewage | | | 19 | 78 | 41 | 89 | | | 7 | 70 | 20 | 82 | 29 | 85 |
| Colloids, etc., removed | | | ·50 | 4·39 | 1·08 | 4·94 | | | ·20 | 3·44 | ·25 | 4·18 | 1·00 | 4·41 |
| Free and saline ammonia | 5·72 | 5·72 | 5·72 | 4·26 | 4·57 | 1·43 | 3·80 | 3·80 | 3·71 | 3·00 | 3·71 | 2·21 | 3·71 | 1·00 |
| Per cent. reduction | | | 0 | 25 | 20 | 75 | | | 2 | 21 | 2 | 42 | 2 | 74 |
| Albuminoid ammonia | 2·01 | 1·50 | 1·37 | ·42 | 1·03 | ·15 | 1·62 | 1·16 | — | ·50 | — | ·265 | — | ·18 |
| Per cent. reduction calculated on — Raw sewage | | 25 | 31 | 79 | 48 | 92 | | 28 | | 69 | | 84 | | 89 |
| Settled sewage | | | 9 | 72 | 31 | 90 | | | | 57 | | 77 | | 85 |
| Nitrite and nitrate (in terms of $NH_3$) | | | ·03 | ·04 | ·06 | 1·22 | | | nil | ·10 | nil | ·50 | nil | 1·14 |
| Per cent. of ammonia oxidised | | | 1 | 1 | 1 | 21 | | | 0 | 3 | 0 | 13 | 0 | 30 |

## Table X.

*Effect of Sterilisation of Sludge.*

| | Raw sewage | | Diluted* raw sewage | Sewage (diluted)* alone. | | | | Sewage + sterile sludge. | | | | Sewage + active sludge. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Original. | After aeration for | | | Original. | After aeration for | | | Original. | After aeration for | | |
| | Shaken. | Settled. | Shaken. | Settled. | 3 Hrs. | 9 Hrs. | 18 Hrs. | Settled. | 3 Hrs. | 9 Hrs. | 18 Hrs. | Settled. | 3 Hrs. | 9 Hrs. | 18 Hrs. |
| 4 Hours oxygen absorption — Total | 11·77 | 8·10 | 8·20 | 6·12 | 5·92 | 5·43 | 3·77 | 10·00 | 10·52 | 10·17 | 7·20 | 4·12 | 1·63 | 1·20 | 1·14 |
| Crystalloids | | | | 3·88 | 4·00 | 3·54 | 2·86 | 5·63 | 5·76 | 5·26 | 3·40 | 2·50 | ·94 | ·77 | ·77 |
| Colloids, etc. | | | | 2·24 | 1·92 | 1·89 | ·91 | 4·37 | 4·76 | 4·91 | 3·80 | 1·62 | ·69 | ·43 | ·37 |
| Free and saline ammonia | 3·30 | 3·30 | 2·95 | 2·86 | 2·86 | 2·36 | 2·07 | 2·95 | 2·86 | 2·64 | 2·50 | 2·95 | 2·71 | 1·72 | ·57 |
| Albuminoid ammonia | ·87 | ·42 | ·01 | ·315 | ·305 | ·33 | ·26 | 2·50 | 2·23 | 2·04 | 1·81 | ·215 | ·105 | ·12 | ·105 |
| Nitrite and nitrate (in terms of $NH_3$) | | | | ·06 | ·06 | nil | ·03 | ·12 | nil | nil | nil | ·09 | ·12 | ·58 | 1·14 |

* Original sewage diluted with a volume of water equivalent to the volume of sludge employed in the experiment.]

In the absence of any other altered factor this decreased efficiency might reasonably have been ascribed to the fact that while in the previous experiments any particular sample of sewage was always aerated in contact with the activated sludge for from 20 to 24 hours to ensure complete nitrification, in the present case, at the end of first six hours' aeration the purified liquor was replaced with a further sample of sewage.

Unfortunately, however, during the course of this series of experiments, low temperatures were experienced, not only with the sewage dealt with, but also in the laboratory, owing to trouble with the heating apparatus.

It was thus impossible to say to what extent, if any, either of these two factors influenced the results obtained, and instead of continuing sectionised experiments on these lines, attention was diverted to the study of the questions involved.

Before leaving this part of the subject it may be stated that while the above experiment failed to determine the possibilities of sectionising the oxidation process the matter has not been lost sight of, and it is the intention of the authors to return to this question at an early date.

*Maintenance of Sludge Activity.*

In order to determine how far the purification effect of the activated sludge was influenced by not carrying the oxidation process to complete nitrification the following experiment was carried out.

Activated sludge of known efficiency was divided into four equal volumes and placed into separate bottles, viz., A. B. C. and D. each of four litres capacity and containing a sample of the same sewage.

The following procedure was then adopted :—

*Bottle A.*—Sewage aerated for six hours in contact with activated sludge, followed by two hours' settlement, sample of purified effluent taken, remaining contents of bottle aerated for 14 to 16 hours longer.

*Bottle B.*—Sewage aerated in contact with activated sludge for ten hours, sample taken at end of six hours.

This operation was repeated twice during the twenty-four hours.

*Bottle C.*—Sewage aerated in contact with activated sludge for six hours, sample taken and purified effluent removed as in A. Sludge was then aerated for the remainder of the day.

*Bottle D.*—Sewage aerated for six hours in contact with activated sludge, followed by two hours' settlement and subsequent removal of purified effluent by decantation.

This operation was repeated three times during the twenty-four hours.

It will be seen that with similar aeration the sludge in bottle D. dealt with three volumes of sewage to two volumes in case of bottle B. and one volume in the case of bottle A., while the sludge in bottle C. also only dealt with one volume of sewage, but the amount of air required for aeration was reduced by the fact that for from 14 to 16 hours the sludge alone was aerated.

A series of results obtained during the course of this experiment are given in Table 4 (p. 528).

The results of the first experiment of this series (Experiment 54) are given in order to show that the activity of the sludge in each case was identical. As the experiment proceeded, while the oxidation effect as measured by the oxygen absorption test differed only slightly according to the method of working, a marked difference was observed in the amount of nitrification. In the case of the sludge contained in Bottle A., which only dealt with one sample of sewage per day, the nitrification was maintained as in the first experiment, but in each of the other methods of working the nitrification was seriously impaired, in fact almost inhibited.

It was observed, however, that the sludge in Bottle C. after the removal of the oxidised effluent, had not been well aerated during the period of working. Accordingly means were adopted to improve this aeration. The results obtained during the second and third week's working, of which typical examples are given (Experiments 59—66) show that the effect of this improved aeration was to maintain the activity of the sludge and consequently to yield similar results to those obtained when the whole of the sewage and sludge was aerated for 22 hours.

It will be seen that the results obtained with the sludge contained in Bottle D. gradually deteriorate with the total inhibition of nitrification. In the case of the sludge in Bottle B. the falling off in its activity was not so marked, although the nitrification was considerably reduced.

It is evident from the results of this experiment that the activity of the sludge is gradually diminished, when working on the fill and draw method, if it is called upon to treat further samples of crude sewage, prior to the complete nitrification of the previous sample dealt with.

The results also show that this difficulty may be overcome by simple aeration of the sludge alone, until the free and saline ammonia content is removed.

*Influence of Temperature.*

In order to determine the influence of temperature on the oxidation process a series of experiments extending over several weeks were carried out on the aeration of Manchester sewage in contact with activated sludge at temperatures varying from 5°—30° C. A number of typical results are given in Tables 5, 6 and 7 (pp. 529—531).

It should be mentioned that in all the experiments quoted in this section of the work, the activated sludge dealt with one volume only of sewage per day. Samples were taken after three, six and nine hours' aeration respectively and then aeration was resumed until the next dose of sewage was treated.

It was found that the oxidation process could be maintained within a fairly wide range of temperature. At temperatures constantly below 10° C. a very marked deterioration in the results was observed, especially with regard to the removal of the colloidal matters. Also nitrification was practically inhibited within a period of nine hours' aeration. It is fairly evident that this effect would be accumulative over a prolonged period of working with the probable eventual production of inactive sludge.

At temperatures varying from 12—14° C., which is the usual air temperature of the laboratory, the activity of the sludge was well maintained with the production at all times of a satisfactory effluent.

It was further observed that with a temperature of 20° C. equally good results were obtained as regards the removal of the oxidisable matter and clarification effect, with an increase in nitrification during the later periods of aeration.

Working with temperatures as high as 30° C. it was found that the initial clarification effect was to some extent interfered with and that the effluent resulting from subsequent settlement showed a slight deterioration as compared with that obtained when working at temperatures from 12—20° C. This effect became less marked as the aeration continued and once nitrification was established it proceeded at a slightly increased rate as compared with that obtained at temperatures below 20° C.

*Oxidation of various sewages.*

It was thought of interest to compare the results obtained with Manchester sewage, which contains an undue proportion of a variety of trade effluents, with those of more purely domestic sewage.

Samples of sewage were therefore obtained from the following sewage works :—

| | |
|---|---|
| (a) Moss Side Sewage Works ..... | Urmston |
| (b) Withington Sewage Works ..... | Chorlton |
| (c) Gorton Sewage Works ..... | Gorton |
| (d) Macclesfield Sewage Works ..... | Prestbury. |

In view of the difficulty of obtaining average representative samples of sewage from the above works, it was decided to work with samples of maximum strength, *i.e.*, in each case the samples were taken in the afternoon, and consequently this fact must be borne in mind in considering the results which are given in Tables 8 and 9.

In connection with these results attention should be drawn to the following :—

*(a) Moss Side sewage.*

Experiments on this sewage were carried out in the earlier part of the investigation and consequently the

proportion of activated sludge to the sewage treated was considerably less that in the later experiments. Further in order to more clearly demonstrate the actual oxidation effect of the activated sludge in the control experiment the sewage aerated alone was diluted with a volume of tap water equal to that of the sludge employed in the experiment. The analytical figures given for the shaken sample of sewage refer to the sample actually taken plus the diluting water.

*Sample A.*

This was a Monday afternoon sample, and obviously contained an excessive amount of soapy matter. It will be seen from the table that this soapy matter exerted a considerable emulsification or deflocculation effect as shown by the increase in the four hours' oxygen absorption and albuminoid ammonia of the "original" settled sample after mixing with the activated sludge, and in consequence of this effect the results obtained were not so striking as the previous ones, although considerable nitrification was obtained within six hours. It would appear that in the case of sewages containing undue proportion of soapy matter, preliminary treatment with lime might be advantageously employed.

*Sample B.*

It will be seen from the analytical returns that this was a stronger sewage than the preceding one, but contained less soap. In this case no preliminary emulsification was observed and a much greater purification was effected in the earlier stages of aeration.

*(b) Withington sewage.*

The sewage from the Withington works was considerably weaker than that received from the Moss Side works and consequently as would be anticipated, complete oxidation ensued within a greatly reduced period of aeration. It may be noted that two hours' aeration in contact with activated sludge, with subsequent settlement was sufficient to produce an effluent which was non-putrefactive on incubation.

*(c) Gorton sewage.*

It is evident from the analysis given in Table 9 that the sample dealt with was an exceedingly strong sewage. With three hours' aeration a remarkable change was effected as measured by the usual tests. After six hours' aeration an extremely well clarified effluent was obtained, but unfortunately owing to an accident it is not possible to give the chemical analysis.

Despite the highly concentrated nature of this sewage 9 hours' aeration was sufficient to yield an entirely satisfactory effluent showing a rather higher percentage purification on the raw sewage than that which is yielded by efficient bacterial filters. Within a period of 9—18 hours the whole of the free and saline ammonia was removed from the sewage.

*(d) Macclesfield sewage.*

The sample of Macclesfield sewage was very turbid and was said to contain waste refuse of a mucilaginous character derived from silk works. With this type of sewage the oxidation proceeds satisfactorily although the percentage purification effected is not quite so good as in the case of Gorton sewage. A well clarified effluent was obtained with six hours' aeration in contact with activated sludge and subsequent settlement. The whole of the free saline ammonia was removed within a period of sixteen hours.

*Quality of effluents.*

It has frequently been observed that effluents obtained from the oxidation process, while having a comparatively low oxygen absorption as measured by the permanganate test and a low albuminoid ammonia content, may absorb an undue proportion of dissolved oxygen on incubation for a number of days. When once the free and saline ammonia content of an effluent is very considerably lowered even without material alteration in the four hours' oxygen absorption and albuminoid ammonia figures, the amount of dissolved oxygen absorbed by the effluent is enormously reduced. It would thus appear that the stage to which nitrification has advanced is one of the factors governing the amount of dissolved oxygen absorbed by an effluent. Experiments are in progress with a view to throwing further light on this subject, but the data so far available is insufficient to allow of any definite conclusions. It is quite certain however, that in the effluents obtained, the amount of oxygen absorbed from permanganate bears no relation whatever to the amount of dissolved oxygen absorbed.

*Activated sludge.*

Activated sludge accumulated in the manner previously described is quite inoffensive, dark brown in colour and flocculent in character, and despite its low specific gravity separates from water or sewage at a rapid rate. After prolonged settlement the activated sludge however rarely contains less than 95 per cent. of water.

A remarkable separation of the water from the sludge can be readily obtained by treatment on fine grade strainers with the production of a sludge of the consistency of a stiff jelly.

Gelatine counts have shown a bacterial content of at least 30 million organisms per cubic centimetre. In addition, the sludge by reason of its nitrifying power must of necessity contain a large number of nitrifying organisms.

It should also be noted that a fairly large number of a variety of protozoa are to be found and we are indebted to Mr. James Crabtree for assistance in regard to the enumeration and identification of these higher forms of life. It does not however contain any algal growths.

The chemical analysis of an average sample of the activated sludge is as follows:—

| | Percentage. |
|---|---|
| Organic matter | 64·7 |
| Mineral matter | 35·3 |
| Total nitrogen (N) | 4·6 |
| Phosphate ($P_2O_5$) | 2·6 |
| Matter extracted by $CCl_4$ | 5·8 |

Attention should be drawn to the abnormally high percentage of nitrogen as compared with ordinary unoxidised sewage sludge.

*Nature of reaction.*

Up to the present the authors have not seriously investigated the actual mechanism of the process and consequently no attempt has been made to differentiate between the part played by physical, chemical and biological agencies, all of which are doubtless, in varying degrees responsible for the total purification change. As to whether the protozoa content has any influence or not on the extent of the purification has yet to be determined, although it would appear that they rather indicate a particular condition of the activated sludge than play an important part in the changes effected.

While as previously stated no serious attempt has been made to determine to what extent bacterial agencies are concerned with the purification process, an experiment has been made on the effect produced by the aeration of sewage in contact with activated sludge both before and after steam sterilisation.

The results of this experiment are given in Table 10, from which it will be seen that activated sludge when sterilised under these conditions had no purification effect whatever (see p. 533).

It must be borne in mind, however, that the physical characteristics of the activated sludge may be seriously altered by the steaming process and consequently some other method of sterilisation, *e.g.*, by means of ultra-violet rays might yield somewhat different results.

*Summary and Conclusions.*

The foregoing investigations have established:

1. That the resultant solid matter obtained by prolonged aeration of sewage, which has been termed activated sludge, has the property of enormously increasing the purification effected by simple aeration of sewage, or in other words it greatly intensifies the oxidation process.

2. The extent of the accelerating effect depends upon the intimate manner in which the activated sludge is brought into contact with, and upon its proportion to, the sewage treated.

3. That in order to maintain the sludge at its highest efficiency it is necessary that there should not be at any time an accumulation of unoxidised sewage solids.

It is not necessary that the sewage should be kept in contact with the activated sludge until such conditions obtain, as its activity may be maintained by suitable aeration of the activated sludge alone.

4. That temperature exerts a considerable influence on the oxidation process. The purification effected is seriously diminished at temperatures constantly below 10° C. Up to 20—24° C. no material difference in the clarification effect and general purification has been observed although the nitrification change proceeds more rapidly as the temperature rises. At higher temperatures the clarification effect is somewhat interfered with during the earlier period of aeration, with a consequent delay in the establishment of nitrification. Subsequently the rate of nitrification somewhat increases.

5. That under the conditions of experiment a well oxidised effluent can be obtained by the aeration of average strength Manchester sewage in contact with activated sludge for a period of from six to nine hours. The percentage purification effected as measured by the usual tests is at least equal to that obtained by the treatment of sewage on efficient bacterial filters.

The period of aeration naturally depends upon the strength of the sewage treated and the degree of purification required.

6. That the activated sludge differs very considerably in character and composition from ordinary sewage sludge.

It is in a well oxidised condition and consequently entirely innocuous, can be readily drained on straining filters and possesses a high nitrogen content.

The scope of this inquiry has been up to the present largely confined to laboratory investigations and while the results obtained have shown conclusively that the purification process can be readily maintained, a large amount of further research is required in order to obtain a thorough knowledge of the character and mechanism of the changes taking place, which will be essential for the efficient control of the process.

The method employed in producing a satisfactory purification of sewage is however of so simple a nature, that there would not appear to be any insuperable difficulties in translating the experiments described, on to a working scale.

In view of the obviously great reduction in the area of works required and capital expenditure involved, the available data in regard to the probable cost of aeration is such as to lend encouragement to the idea that the adoption of aeration methods on the lines of these experiments would result in a considerable reduction in the total cost of sewage purification. In this connection it may be reasonably anticipated that the enhanced value of the resultant sludge should at least cover all costs incidental to its disposal.

In conclusion the authors wish to express their sincere thanks to Dr. Fowler for the suggestion which originated this inquiry, and for the keen interest with which he has followed the whole series of experiments.

They are indebted to the Rivers Committee of the Manchester Corporation for permission to publish the results of this investigation, which has been carried out in the laboratory at the Corporation Sewage Works, Davyhulme.

## Discussion.

Dr. J. Grossman said that the sludge question had entered upon a phase in which, though it was not expected to produce a large profit, it was to a certain extent capable of commercial treatment. Where the present processes of purification might be barred by local circumstances the process described in the paper if successful would be greatly in advance of what was being done at present. No doubt, in some instances it would become a commercial question as to whether aeration by means of activated sludge would be more economical than any of the other processes of purification and the mechanical element would enter very largely into this question. He had been very much struck with the amount of nitrogen in the sludge. Was this partially due to the elimination to a greater extent of the detritus matter than was usual with ordinary sludge? Perhaps the authors could give them some information as to the average amount of nitrogen in ordinary Manchester sludge. Assuming even as much as two per cent. of nitrogen on the dry sludge then the 4 or 4½ per cent. of nitrogen shown could not be accounted for by a larger quantity of detritus having been taken out. Even if they took into consideration the ammonia being utilised by the bacteria, he could not understand how an increase of nitrogen could be obtained because the bacteria were supposed to oxidise the ammonia into nitrates which were soluble, unless the bacteria took up the nitrogen from the air and used it for building up their own bodies which afterwards remained in the sludge.

Mr. F. R. O'Shaughnessy regarded the paper as an epoch-making one, provided that the process experimentally established by the authors could ultimately be applied on the large scale at a reasonable cost. After all, from the point of view of the man-in-the-street—the man who paid the rates—the financial question was one of the first questions. The process suggested by the authors would greatly reduce the area of the works and would probably go far to eliminate nuisance, and these too were very important considerations from the public point of view. In Germany sewage was often merely precipitated or sedimented and the sewage liquor then passed through open channels for many miles to the nearest river. The Germans seemed to have no objection to this, but in England such a procedure would not be tolerated.

Apart, however, from such general and practical considerations, the scientific interest of the paper could not be over-estimated. So far as he could judge, the main principle at work did not differ substantially from that which obtained in an ordinary bacteria bed, viz., exposure to the necessary organisms in presence of an excess of oxygen. The experiments demonstrated that there must be considerable surface contact between the liquor to be purified and the "activated" sludge. The action was undoubtedly a very complex one. Merely physical effects in the way of flocculating the colloidal and finely divided suspended solids would be obtained which would help in clarifying the liquor. The destruction of the colloidal character of the sludge was no doubt brought about by biological agents and it was interesting to note that at a temperature of 30° C. a process of deflocculation went on.

Recently he had read a paper before the Institute of Sanitary Engineers giving a number of observations bearing on these points. Many engineers apparently held the view that the so-called "colloiders" precipitated colloidal matter by virtue of their physical action. This view was erroneous, for these "colloiders" were efficient only because they provided a habitat for the micro-organisms which were the effective "colloiders." Not till the sewage liquor had an enormous surface presented to it, as in a bacteria bed, did physical forces remove any appreciable quantity of impurities from the liquor. The great advantage inherent in the process outlined by the authors of the present paper was that aerobic conditions prevailed and foul products were thereby eliminated.

His observations on these phenomena extended over many years and the following figures which were the averages of many analyses over a lengthy period made on the Birmingham sewage under working conditions on the large scale were correspondingly very reliable. He had taken the "oxygen absorbed in four hours" figure on the liquor freed from visible suspended solids as an index as to what happened. This figure for the crude sewage liquor was 17·10 parts per 100,000, and after passing through a plain rectangular sedimentation tank where the time of sojourn was four to five hours the liquor then gave the figure 13·71. A remarkable point was that 20 per cent. of the dissolved impurities were removed by this simple means. Further treatment of the liquor for six hours in a septic tank reduced the figure to 12·53. After that the liquor passed through a five-mile-long sewer

and the above figure was reduced by a six hours sojourn in this sewer to 9·11 parts per 100,000. The surface to which the liquor was exposed in this sewer was very considerable and the colloidal matter was precipitated to an appreciable extent on this journey, whilst the suspended matter was correspondingly increased. This suspended matter was arrested in upward flow conical tanks and the figure for the clear liquor issuing from these tanks fell from 9·11 (above) to 8·71 parts per 100,000. Passage through a percolation bed then reduced the figure to about two parts per 100,000 in ½ to 1 hour.

If the above observations were set out as rates per hour of elimination of impurities in solution the result became very striking. These rates were as follows:—

| | | |
|---|---|---|
| On the sedimentation tank | 0·68 | parts per hour. |
| ,, ,, septic ,, | 0·20 | ,, ,, ,, |
| ,, ,, five-mile sewer | 0·70 | ,, ,, ,, |
| ,, ,, upward flow tank | 0·28 | ,, ,, ,, |
| ,, ,, percolation bed, about | 10·00 | ,, ,, ,, |

The total purification of dissolved oxidisable impurities by 22 hours tank treatment was about 50 per cent. and was greater under "septic" than under "non-septic" conditions.

In another set of experiments on the large scale the sewage was divided into two portions each portion passing through two separate sets of tanks. One portion was treated with two parts per 100,000 of bleaching powder and the other untreated. The chlorinated liquor was sterilised by the treatment, and no change took place in the figure for "oxygen absorbed" owing to passage through the tanks, whilst on the other hand an appreciable drop in the dissolved oxidisable impurities occurred in the liquor passing through the other set of tanks to which no bleaching powder had been added. These observations had a bearing on the process brought forward by Messrs. Ardern and Lockett, for they threw some light on the nature of the action. Broadly, his conclusions were that the grosser colloidal matters held by sewage liquors came down readily in ordinary continuous flow sedimentation tanks, that the great bulk of the colloidal matters—say 70—80 per cent—were held very tenaciously by the sewage liquor and were only removed by either biological agents, or physical forces suitably applied such for instance as in a well constructed and properly worked bacteria bed. In ordinary modern works practice probably the biological factors were the most potent, and the experiments carried out by the Authors indicated that this held good with respect to the new process they described.

One other point he wished to refer to was the part played by the nitrogen in these phenomena. He agreed with the authors that this behaviour was rather puzzling, and much work remained yet to be done on this most important aspect of the question.

Mr. S. E. Melling thought the process described was ideal inasmuch as it resolved itself into a single-tank treatment. The greatest bugbear to the sewage problem had been the question of sludge disposal. By means of the new system the sludge, activated in the manner described, became the friend rather than the enemy of the sanitary scientist. Had there been any estimation of the percentage of nitrogen during the different stages of the development of activity of the sludge it would be interesting to learn by what stages the fixation of the nitrogen took place. He observed that the carbon tetrachloride extract was put down as grease. Had any approximate examination been made of that extract, as it would be distinctly against the value of the sludge as a manure if the grease was left in? The whole scheme appeared to be one of great value for communities with very small available spaces of land at their disposal. If it was possible to have the carbonaceous fermentation carried out successfully in a preliminary tank, whether it was in the nature of a "roughing" tank or filter, or similar existing device, and so bringing the effluent to the stage where, by passing it through aerating-filters the necessary nitrification could be attained, a great saving could be effected. The filters could be fed four to six times their usual speed. An interesting point occurred in connection with the disappearance of nitrogen, where in some cases the oxidised product did not at all correspond with the free ammonia. According to one of the tables shown it would seem that the best dilution for the oxidation-cycle to proceed, regularly and completely, was 1 : 12. Might there not be some feasible explanation of the loss of nitrogen when the ratio of activated sludge to sewage was much higher?

Mr. Percy Gaunt said that the method of treatment suggested might offer advantages sufficient to compensate for any additional power required for the aeration process, in view of the reduced area required, and the possibility of reduction of the nuisance from smell and from flies. Under the present system, even when circumstances favoured a fairly compact scheme, an area of ten acres would usually be required for the disposal works of a town of about 40,000 inhabitants, when due allowance had been made for the selection of a site providing the fall of several feet, necessary for a filtration process. The experiments described suggested the possibility of reducing the area by about eighty per cent., and the necessary fall to a few inches. A suitable site under existing conditions might be two or three miles from the town, entailing an independent power installation, whereas with the reduced area and diminished fall requirements of the suggested method, full advantage might be taken of any cheap power (such as a town gas, or electricity supply) in choosing the position of the works. Interesting information as to the relative importance of the physical and biological factors in purification might be obtained from comparative aeration experiments conducted (a) under ordinary conditions; (b) in the presence of ultra-violet rays.

Mr. Johnson inquired whether the sludge contained any ammonia, and also what quantity of air was required.

Mr. J. T. Thompson said that one striking feature of the new process was that it was aerobic from beginning to end, and it was probable that the amount of smell would be negligible. If these laboratory results could be economically obtained on a large scale the present elaborate system of dealing with sewage would be simplified; the cost of pressing sludge, depositing it in the sea or in trenches on land would be avoided, for activated sludge evidently dries rapidly and would yield good manure. This process might also reduce the area of bacteria beds needed. What volume of air was it necessary to blow through the mixture, for this would be a costly item in practice? He presumed there would be some limit below which the sludge would not be sufficiently mixed with the supernatant liquid to complete the oxidation in a reasonable time. With regard to the high nitrogen figure in the activated sludge, if possible, he would like to have an analysis of ordinary Manchester sludge to compare with the sample of activated sludge.

Mr. Hart (Leeds), speaking as an engineer, thought the process would resolve itself into a question of the relative cost of manipulation of the sludge either as liquid or solid matter. He admitted that the difficulty from the engineering side at the present time was to find a satisfactory method of manipulating the sludge for useful manurial purposes at a reasonable cost. At the moment he could not see that there was a probability of there being any great saving in costs of manipulation. The present experiments were, however, laboratory experiments, and it would be necessary to deal with sewage and sludge in bulk before any reliable data could be furnished as to cost.

Dr. G. J. Fowler said that a considerable time ago Mr. Ardern and himself read a paper before the Society on suspended matter in sewage and effluents, which raised in a simple way a question which had found its final expression in the paper they had heard that night, that was to say the flocculation of colloidal matter. The end had not been reached at once. There had been a number of stages, and a great many minds had been at work on the question. When he had the honour of delivering the Chairman's address before the Section he mentioned the idea of Dr. Maclean Wilson of an enzyme which might clot out sewage and produce the effect which now took place in a percolating filter, and ventured to suggest that it might be possible to find something of the kind. An experiment was tried with some of the deposit from a filter,

blowing it up in sewage, with apparently little result. Other chemists had tried the same experiment. It was only right to admit that the illuminating idea which originated the work was really due to a visit he had paid while in the United States, to the Mecca of sewage purification, namely, the experimental station at Lawrence in the State of Massachusetts, where he saw the bottle, described in the paper, in which sewage had been completely purified by 24 hours' aeration. The idea at that time, and subsequently in the experiments which had been published from that laboratory, involved the principle of surface. He discussed some of the possibilities of the method with the President of the New York Sewerage Commission, and that gentleman was of the opinion that the idea of surface should be abandoned if possible if the matter was to be really advanced. They also discussed the question of the clarification of sewage. The problem at New York was to deal with some 1,000 million gallons of sewage per day and the idea of sprinkling such a large quantity about in the atmosphere in the hot American summer did not seem to be altogether practicable. In the intervening time other experiments had been made by Mr. Mumford and himself with regard to the clarification of sewage bacterially, and they had succeeded in clarifying altogether about 10,000 gallons by means of a process which had already been published. As Dr. Grossmann had observed, local conditions had to be taken into consideration. It was also necessary to consider the process of sewage purification on the one hand and the utilisation of the nitrogen and other constituents on the other. The process described in the paper aimed at purifying the sewage as rapidly and as simply as possible. He, for his own part, believed that the process was practicable on a large scale, and they would have some idea of what that meant when he mentioned that the settling tanks at Davyhulme were constructed to hold 21 millions gallons. The results indicated in the paper showed that some six hours' blowing would produce an effluent equal to the final effluent at present obtainable; that was to say, complete purification in six hours. Assuming that the operation was only carried out twice in the 24 hours, allowing six hours to blow and six hours for the manipulation Mr. Hart had spoken of, aerating the sludge and so forth, it meant that in the tanks available 42 million gallons per day could be purified. The consequent saving of space and expenditure on filters would be something enormous, and would allow for quite a large expenditure on power and otherwise for the provision of air. He would not commit himself to figures that evening. It would not be a wise proceeding at that stage. The question of cost had been very carefully considered, and the whole matter had been approached from a number of points of view. Estimates had been obtained for large scale-work in blowing and so forth. He had consulted Mr. S. L. Pearce, the Chief Engineer of the Manchester Corporation Electricity Department, with reference to the amount of power required for providing a certain amount of air, estimating for the greatest quantity of air conceivable for the purpose, and recent work which had been begun showed that there had been an over-estimation in that direction. Taking everything together he was convinced that the process was a practical proposition. In order to carry it out by the most economical method possible it was, of course, necessary to call in the aid of their friends the engineers. Figures as to cost had been published by experimenters in America. In a paper by Messrs. Clark and Adams, published in the "Engineering Record," the figure for electricity was placed at 2d. per unit, which was not very cheap, and on that basis the cost of air was given at 8s. 4d. per million gallons. The American sewage was rather dilute. There was also cost of the slate surfaces. Still, if it was possible to carry on the process at the cost of 8s. 4d. per million gallons the matter appeared to be quite practicable. It was necessary to get the principle right in the first place, and on that point he had no doubt. The idea was really nothing new in a way. All that was happening was that instead of running the stream of sewage over a filter bed with imperfectly oxidised sludge one took activated sludge and moved it about with complete aeration. In the same way that a percolating filter was a concentration of land treatment so the treatment described was a further concentration on the percolating filter. No really new principle was involved, and for that reason it appeared to him the thing was on right lines. Regarding the question of nitrogen which had been raised, his view was that the organisms collected a certain amount of nitrogen from the products present in solution and built up a certain amount of protoplasm thereby. He was confirmed in this opinion by experiments made at the Manchester University, where a deposit was obtained containing even more nitrogen than was indicated in the paper. The amount of mineral matter in activated sludge was not high. It would be necessary in order to secure success that very careful means be taken to remove the grit, and considerable engineering skill would be required to design really satisfactory grit chambers. There were no such things in existence in the world at the present time, but no doubt the problem was capable of solution. The complete removal of grit would materially assist the working of the process. The research work carried out by Messrs. Ardern and Lockett opened out possibilities which would re-awaken the public interest in the sewage problem, which, perhaps, to some of them had latterly become somewhat of a bore by being standardised to such an extent that the whole question had become one of routine. The authors of the paper had now fired a bombshell into the camp, and perhaps they would all start on new ways in the future.

Mr. Ardern, in reply, said that no means had been taken to remove the detritus from the sewage which was generally the average 24 hours' sample. An inspection of the analysis would show that the percentage of organic matter in the resulting sludge was 65 per cent. or thereabouts, whereas the usual percentage of mineral matter in sedimented sludge in the case of Manchester would be about 50 per cent., so that there was a considerable increase in the organic content. With regard to the high percentage of nitrogen, the figure given was the mean of several determinations. It would appear that the high nitrogen content was due to a large extent to the flocculation of the fæcal emulsion. There had been no determinations of nitrogen at different stages of the accumulation of the sludge. There were still a number of points requiring elucidation, and it was not suggested that investigation had been made into every operation that actually took place. What had been done was to endeavour to obtain results which could be readily maintained under conditions in which apparently there should be no serious difficulty in translating to a practical working scale. The scientific side of the matter had only been dealt with in a limited manner. The authors agreed with Dr. Fowler in regard to the principle of the process which he had dealt with in the course of his remarks. As stated by Mr. O'Shaughnessy, with a temperature of 30° Cent. there was apparently a slight deflocculating action on the sludge, but it was not maintained, the effect being observable in the initial stages, flocculation subsequently occurring. No examination had been made of the grease extract, as at the time the determination was made the activated sludge was rather a valuable product from the experimental point of view. He was of opinion, however, that the percentage of fatty matter present was not sufficient to militate against the use of the sludge as a fertiliser. It was a considerably lower percentage, as Dr. Grossmann would be aware, than in the case of ordinary sewage tank sludge, even counting the whole carbon tetrachloride extract as grease. It was quite common for ordinary tank sludge to contain 10 to 15 per cent. of grease extract, and possibly in some cases a greater quantity. There was no definite explanation to offer in connection with the loss of the nitrogen, and there was no doubt that with regard to the conservation of that constituent further information was required. In the earlier experiments almost quantitative nitrification of ammonia was obtained. This did not apply to the later experiments where there was a greater loss of nitrogen. It may be mentioned that during the later experiments a greater volume of sludge was employed, and nitrification proceeded at a more rapid rate which might possibly have some influence on the liability to losses of nitrogen. The question of the effect of waste liquor from sulphate of ammonia plants had not been investigated. The Manchester sewage

dealt with, however, contained from 0·5 to 1·0 per cent. of this trade effluent, and in this proportion no serious retarding effect on the oxidation process was apparent. If, as appeared probable, the process was essentially bacterial, there was no doubt that any serious amount of inhibiting matter, of whatever type, as long as it was bactericidal, would doubtless have to some extent a deterrent effect. The volume of air required was a point which obviously was connected with the cost of the aeration process. They had not gone very deeply into the matter. As a matter of fact the laboratory experiments had been aerated without consideration of the question of cost. They had determined the volume of air used in the experiments, which was evidently much in excess of that actually required; the quantity amounting to something about one-fifth of a cubic foot per square foot of tank area per minute. While Dr. Fowler naturally refrained from giving any figures, one could say without hesitation that the quantity of air required was very much less than that allowed in any calculations he had made. In the laboratory experiment the air was used not only for aeration but also as a means of agitation, and it was quite conceivable that a combination of mechanical agitation with the use of air for aeration purposes only would be more economical. That, of course, remained to be seen. A question had been raised as to the effect of grease, concerning which he could not give any information. Whatever grease there was in the average sample was in the sewage when they treated it, and there was no apparent hindrance to the oxidation process. At no time was there an excessive quantity of grease, but he was of opinion that some simple means would be adopted for removing any actual grease from the sewage before subjecting it to any such treatment.

The main feature of the experimental work was the satisfactory purification of sewage by tank treatment alone, with the production of a sludge which, owing to its oxidised and flocculent condition, could be readily dealt with and converted into a valuable fertilising agent.

A number of samples illustrating the experiments of the authors were exhibited.

## Obituary.

HERMAN FRASCH.

Herman Frasch was born in Gaildorf, Würtemberg, in 1851. In 1868 he went to America and soon attained the foremost position in the Laboratory of Prof. Maisch of the Philadelphia College of Pharmacy. In a short time, however, he turned his attention to chemical industry, and acting quite independently, he commenced a series of investigations bearing upon the subject of petroleum and its products. In 1876, at the age of twenty-four, Frasch evolved a process for refining paraffin wax, which so pleased the directors of the Cleveland Petroleum Company, that they purchased it, and the young chemist was induced to leave Philadelphia and go to Cleveland, and make the petroleum industry his speciality. Numerous patents were now taken out by him. These were not all confined to petroleum and its products, for in 1882, he patented a process for making white lead directly from galena, and between 1882 and 1886 one for making sodium carbonate from salt by the ammonia process, besides others in connection with practical applications of thermo-electricity. In the works of the Empire Oil Company, Frasch solved the problem of purifying the offensive sulphurised petroleum oils of Canada and Ohio, thus raising them to a high degree of purity. In 1888, the Standard Oil Company bought his patents after exhaustively testing their value. One of Frasch's greatest achievements was his ingenious process for recovering the sulphur from a huge deposit in Louisiana, 1000 feet down in the earth and covered by dense layers of sand. Heat was applied to the sulphur *in situ* by means of superheated water forced down a boring, first fusing and then impelling the melted sulphur up an inner tube to the surface (see this J., 1912, 168—169). He applied for 10 patents for processes and apparatus in this connection. Now, thanks to Frasch's inventive genius, sulphur (formerly shipped from Sicily to America), is exported in large quantities from America to Europe. Frasch ultimately became President of the Union Sulphur Company of New York and Hamburg, and of the International Sulphur Refineries of Marseilles. Two years ago, at a Meeting of the New York Section of this Society, Prof. Chandler, in presenting to him the Perkin Gold Medal of the associated Chemical and Electrochemical Societies, said, the "Perkin Medal Committee felt fully justified in placing Mr. Frasch by the side of William H. Perkin, as one of our greatest industrial chemists and chemical engineers."

He died May 1st, 1914, in Paris, at the age of 63.

# Journal and Patent Literature.

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## I.—GENERAL PLANT; MACHINERY.

PATENTS.

*Taking samples of powdered or liquid substances; Apparatus for* ——. T. Roberts, Bolton. Eng. Pat. 7354, March 28, 1913. Addition to Eng. Pat. 23,237 of 1911.

VARIOUS mechanical devices for controlling the sampling device of the apparatus described in the chief patent, and clockwork mechanism for operating the controlling device are claimed.—W. H. C.

*Determining by weight quantities of gas, steam or other vapour or liquid; Process and apparatus for* ——. G. A. H. Binz, Enfield. From C. A. Hartung, Berlin. Eng. Pat. 8042, April 5, 1913.

THE resistance for varying the measuring current in proportion to the flow of the fluid in the measuring apparatus described in Eng. Pat. 27,357 of 1911 (this J., 1913, 74) is placed in the circuit before it branches to the resistance bridge, and the resistances which serve to correct for variations of pressure and temperature are placed in the branches of the bridge itself.—W. H. C.