THE ACTIVATED SLUDGE PROCESS OF SEWAGE TREATMENT.

Report on the working of the Plant at the Indian Institute of Science, Bangalore.

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In July, 1922, a new plant for the disposal of sewage by the activated sludge process was installed at the Institute, and has now been treating domestic sewage proceeding from a section of the inhabitants during a period of more than five years. The process is a complete contrast to the older anaerobic methods and is a development of the biological sewage-treatment in bacteria-beds, percolating filters and the like, being aerobic treatment in open tanks. The method depends on the sewage flowing through the tanks being vigorously agitated by finely divided compressed air. The oxygen supplied, in conjunction with the ubiquitous oxidising organisms in the sewage, effects a distinct clarification of the offensive liquid admitted and precipitates all the collodial matter, yielding a valuable fertiliser. This intensive bacterial oxidation is the most up-to-date form of sewage disposal, and has been adopted at the Institute both for sanitary reasons and for large-scale biochemical investigations.

Description of Works.

The installation works on a continuous flow basis. It occupies an area of roughly 1,500 s. ft. and was constructed by a local European contractor to designs prepared by Messrs. Activated Sludge, Ltd., London. The plant was designed for 200 persons at 30 gallons per head per day, or 6,000 gallons per 24 hours. It has, however, been used for nearly 400 persons, the rate per head being about 18 gallons per day. The plant commands 14 acres of ground on which the effluent can be easily absorbed, and was brought into commission on July 10, 1922.

The works comprise tanks for aeration, settlement and re-aeration, built of masonry work and below ground level. The aeration tanks are three rectangular channels 27′ × 2′ × 3′ to water level, subdivided into compartments by vertical baffle walls; the cubic contents are 510 c. ft., equivalent on the designed basis to 2·55 c. ft. per head, Under present conditions it now comes to 1·36 c. ft. per head, taking the number of persons connected to the sewers at 375. The period of sewage-detention was fixed at 4 hours, but subsequently, owing to the varying rates of flow, the actual period has ranged between 3·2 and 5·5 hours. The sewage traverses the whole length of the channels to secure complete aeration and has little chance of short-circuiting; the floors are flat, and aeration is effected by rows of diffusers fitted loosely in grooves at the bottom on one side of the walls.

The settlement tank is 5′ × 5′ × 5′ and ends in a hopper bottom, the sides having a slope of 60° to the horizontal. The depth from the apex of the hopper bottom to the surface is 9′. The mixed liquid proceeds from the aeration-chamber to the centre of the settlement tank through a Clifford inlet inside a guard chamber, and is gently received by a wrought-iron eddy-bucket suspended from two rails fixed to the walls of the tank. The sludge and liquid are here separated, and the purified effluent passes over two weirs on either side of the tank. The Clifford inlet is fitted with a disc-valve normally closed, and opened only when the aeration tanks are drained into the settlement tanks.

The deposited sludge is carried by hydrostatic head from the apex of the hopper bottom through a pipe to the sludge re-aeration channel, similar to the aeration channel but narrower, and also divided into three compartments by baffle walls. At the entrance of the sludge return-pipe there is another disc-valve normally open, and closed only when the aeration tanks have to be drained into the settlement tank and no return sludge is needed in this channel. The sludge from here is raised by an air-lift into the mixing chamber to inoculate incoming sewage with the necessary bacteria. A third disc-valve at the outlet of the air-lift pipe is normally kept open, and closed when surplus sludge has to be pumped out. Another air-lift pumps the surplus sludge into a sump whence it passes through an earthenware pipe into a compost pit.

Air equipment.—The air for agitating the sewage in the tanks is derived from two compressors working alternately. A Reavell compressor working with a three phase induction motor of 3 H.P. delivers a constant supply of 15 c. ft. of free air per minute at 690 r.p.m. This motor works for 15 hours a day, i.e., from 5 p.m. to 8 a.m. A similar motor of 5 H.P. operates a belt-driven Scott compressor and delivers 40 c. ft. of free air per minute at 750 r.p.m. working for 9 hours a day, i.e., from 8 a.m. to 5 p.m. The air delivered can be measured by a curved tube manometer. From July 1922 to October 1923 the Reavell compressor was the only one in operation. After October 1923 the Scott compressor was working and consequently the air supply was increased.

Distribution of air.—The air is distributed by two cast-iron mains fixed to the tank-walls, a slide valve on each main regulating the air supply as desired in any two pairs of tanks. To the mains are attached a number of down pipes, each fixed to a diffuser in a groove at the bottom of the tank. The air-supply to any particular diffuser can be regulated also by a throttle valve. All the air-lifts are worked by compressed air, and the diffusers are of porous material cemented to shallow cast-iron plates.

Operation of the plant.—The tanks were filled and air blown in without admitting more sewage until a sample of the liquid showed good nitrification, the time being a fortnight; a small quantity of sludge was also formed during this period. The entering sewage was purely domestic, and prior to treatment was passed through a system of screens and catch-pits to remove floating solids, heavy detritus and unemulsified material generally. At the mouth of the pipe admitting sewage into the sludge tanks, another wire gauze screen prevented such material as had passed the catch-pits from entering the tanks and choking the pipes. A valve at the inlet pipe regulated the flow and diverted it either completely or partially as required: there was no recorder to gauge the quantity of sewage entering or leaving the tanks.

After complete nitrification of the first filling more sewage was admitted, oxidised and replenished, the process being repeated until there accumulated in the tanks an amount of sludge capable of purifying the sewage in a few hours. In about a month sufficient sludge had been built up, and nitrification was rapid; the Reavell compressor was working from 10 a. m. to 5 p. m. during this period. Sewage was henceforth admitted from 10 a. m. to 1 p. m. and subsequently until 5 p. m. The sludge was chocolate-brown, settled fairly rapidly, and had an earthy smell; the effluent was quite clear and non-putrefactive. Initially the amount of sludge maintained in the aeration tanks was 25 per cent., but early in September, 1922, the larvae of an insect subsequently found to be *Chironomus* rapidly developed and collected all the sludge in small clumps, some of which floated while others became attached to the walls. The floating masses proceeded to the settlement tank and thence passed with the effluent over the weirs. Thus within three days a large amount of sludge was lost. Mechanical disturbance was without effect, and the only way of removing the larvae was to add kerosine, which killed most of them at once while dissipating the red colour. After brushing the particles from the walls and adding a little more kerosine, aeration was renewed, purification of new sewage being effected in less than 24 hours in spite of the large amount of kerosine added. Thereafter the plant worked satisfactorily.

From the beginning of December, 1922, the Reavell compressor was working continuously and early in February, 1923, the plant was treating the full flow of sewage. During this month flow-measurements were made to ascertain the total quantity entering the tanks, successive four-hour periods being kept under observation; 15-minute samples of sewage were taken and flow-measurements made by noting with a stop-watch the time taken to fill a two-gallon measure held under the sewage inlet pipe. Hourly average samples were obtained by mixing portions of the quarter-hour samples in proportion to the flow at the time. Samples of effluent were also collected every hour and an average of the hourly samples also mixed in proportion to the flow. All these samples were analysed for chlorine and for oxygen absorbed from acid potassium permanganate solution in 3 minutes. A complete analysis of the average representative sample was also made. The results are given in Chart I and Table I.

The total flow over a 24-hour period was calculated to be 6,575 gallons. From this table it appears that practically one-third of this flow reached the tanks between 7 and 11 a.m., the maximum rate of flow being 18·6 gallons per minute at 8 a. m. The flow from 11-30 p. m. to 6·30 a. m., did not exceed 0·66 gallon a minute. According to the above calculation, the volume of sewage treated in the tanks from July to December, 1922, amounted to about 436,000 gallons. The ratio of air-supply to sewage during this period was therefore approximately 2·51 c. ft. per gallon. It was however found advisable to adjust the air supply in accordance with the strength flow factor of the sewage (see Table I below) by pumping in more air during the day than at night. The designers of the plant had recommended 50 c. ft. of air per minute for this plant, but actually the sewage was receiving less than one-third of this quantity. The air-supply was purposely not increased in order to study the biological phenomena occurring in the sludge with the available supply. Though stable effluents were obtained with this deficient air-supply the sludge was found to go out of condition within a few months of treating the full flow of sewage. The amount of sludge in the tanks had increased enormously in bulk, was slow in settling and had changed from brown to grey, the whole material being sticky and gelatinous. The volume of sludge in the tanks, usually kept at 25 per cent., increased rapidly to 40 and subsequently to 60, continuing at this value for a period of several days. The reason for this was found to be deficient air supply. The volume of sewage treated before this disturbance, described as 'bulking', was noticed reached 493,000 gallons, and the volume of air per gallon of sewage was 3·3 c. ft. At the end of August in the same year the larvae previously noticed reappeared in such large numbers that the former procedure had to be repeated. The above facts being regarded as due to deficient aeration, a new Scott compressor capable of delivering 40 c. ft. of free air per minute was installed and brought into operation on October 4, 1923. It was also noticed that some sludge was never

TABLE I.

Analyses of average samples of sewage and effluent.

Date	Time	Oxygen absorbed				Chlorine		Amm. nitrogen		Alb. nitrogen		Nitrite nitrogen		Nitrate nitrogen	
		in 3 mins.		in 4 hrs.											
		S	E	S	E	S	E	S	E	S	E	S	E	S	E
14 2 23	6–30 to 11–30 a.m. ...	1·45	0·3	1·84	0·73	4·0	4·0	0·216	0·054	0·08	0·01	nil	0·003	nil	0·5
19 2 23	10–30 a.m. to 2–30 p.m.	1·33	0·26	2·59	0·55	4·31	3·73	0·18	0·033	...	0·023	nil	0·002	nil	1·0
22 2 23	2–30 to 6–30 p.m ...	...	...	5·1	1·22	4·85	4·46	0·24	0·09	0·15	0·03	nil	0·025	nil	0·35
27 2 23	6–30 p.m. to 6–30 a.m.	187	0·35	4·27	1·06	4·93	4·41	0·20	0·15	0·08	0·08	nil	trace	nil	nil
Average	......	1·55	0·303	3·45	0·89	4·52	4·15	0·209	0 082	0·103	0·035	nil	0·008	nil	0·62

S = Sewage. E = Effluent

under proper circulation by the Reavell compressor, deposits of ill-aerated sludge being observed in several chambers and producing denitrifying changes. It was anticipated that this difficulty would be removed by the new compressor.

Careful investigation into the varied aspects of the process were made and except that occasional deposits of silt choked the Clifford inlet-pipe or the return-sludge pipe or the air-lifts, interrupting work for a few hours, no trouble has arisen.

It has been stated that that there is an optimum air supply for activating the sludge in the tanks, higher or lower quantities being disadvantageous (*J. Inst. Eng., India*, 1925, **5**, 75). Experience with this plant has shown that defective air-supply tends to produce a 'sick' or 'ropy' sludge, while excessive aeration, even to the extent of 'burning', has never produced a 'bulked' sludge.

The flow of sewage was again measured in August, 1923, and in February and December of 1924. Except in the last case, where exactly the same procedure as that already described was followed, only the total flow per 24 hours was recorded. The detailed experimental results determined in December, 1924, are given in Chart I and Table II.

TABLE II.

Analyses of average sewage and effluent samples: parts per 100,000.

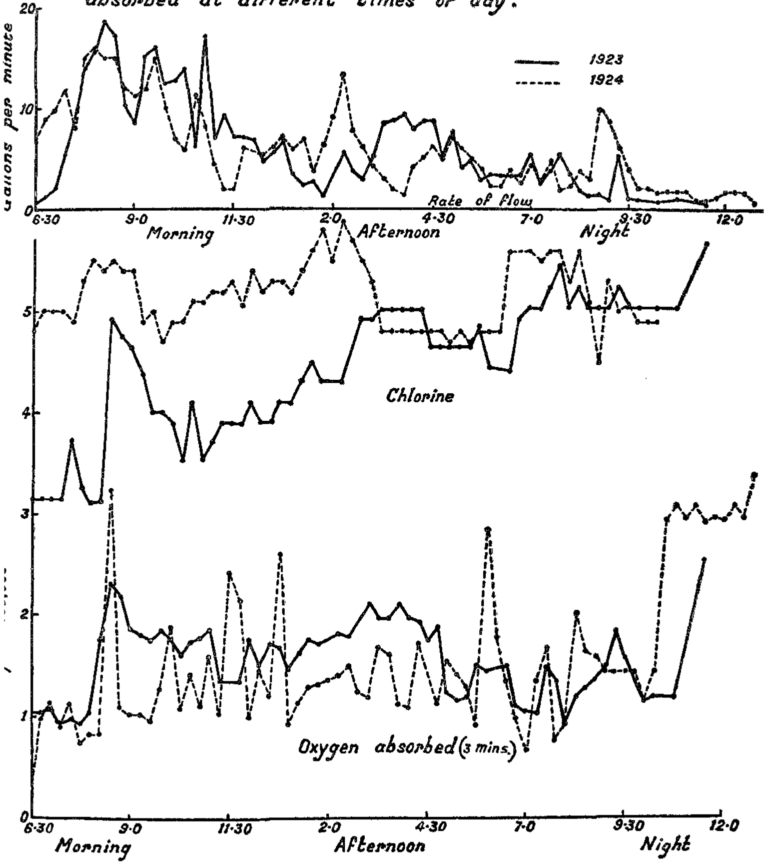
Analysis	Sewage	Effluent	Percentage purification
Oxygen absorbed from permanganate in 4 hrs.	4·23	0·48	88·6
Oxygen absorbed from permanganate in 3 mins.	1·31	0·22	...
Amm. Nitrogen	2·2	0·55	...
Alb. ,, ...	1·87	0·11	94·1
Nitrite ,, ...	nil	0·03	...
Nitrate ,, ...	nil	0·07	...
Chlorine	4·8	4·4	...

Flow Measurements.

Month	*Total flow for 24 hours*
August, 1923	7,250 gallons
February, 1924	4,405 ,,
December, 1924	6,470 ,,

Chart I.

Rate of flow, chlorine content, and oxygen absorbed at different times of day.



The fluctuations in flow were due to (1) variation in the number of persons connected to the sewers and (2) occasional restriction of the water-supply. As before, the greatest flow was in the morning between 7 and 11, and the lowest after midnight when practically no flow could be collected. A glance at Chart I shows the characteristics of the sewage at various periods of the day in the two years. The volume of sewage treated during the several years and the ratio of air-supply to sewage were approximately as follows :—

Year	Total volume in gallons	Air supply in c.ft. per gallon
1922	436,200	2·51
1923	2,162,400	4·39
1924	1,939,800	5·22
1925	2,354,500	5·43

It has been found that, although the ratio of air supply per gallon of sewage treated seems to be very high in the last three years, the circulation of sludge in the tanks was thoroughly effected only when this volume of air was maintained. Occasionally the Scott compressor had to be stopped for short periods owing to the heat generated, when the small compressor was allowed to work; on such occasions we noticed the remarkable difference in the circulation in the sludge. With deficient air-supply the sludge was not maintained in proper contact with the sewage, and purification was incomplete. Various forms of organic life also developed and consequently the sludge lost condition.

Initially 25 per cent. of sludge was kept in the aeration tanks, but subsequent experiments showed that 10–15 per cent. gave results quite as good. Occasionally, with as low a quantity as 8 per cent., satisfactory purification was attained.

The plant was stopped and re-started on two occasions, once in July, 1924 and again in February, 1926. Each time nitrification began more rapidly than previously, being induced in a week the first time and in the second case within 48 hours. Compressor-trouble delayed nitrification in July 1924, but in February, 1926, there was no such difficulty and nitrification began more rapidly. The sludge was also built up in a few days. In both cases the full flow could be successfully treated within a fortnight, and thereafter the plant has worked continuously with only one or two short stops due to failure of current or other fortuitous circumstances.

Chemical control of the process.—Speaking generally, the chemical changes of the sewage consist in degradation of complex protein matter into simple nitrogenous substances. A chemical analysis of the sewage and effluent reveals the character of the sewage treated and the degree of purity attained. The following table gives the figures obtained for the raw sewage and of the effluent from the plant. The results in both cases are averaged from a large number of analyses.

TABLE III.

Analysis of sewage and effluent: parts per 100,000.

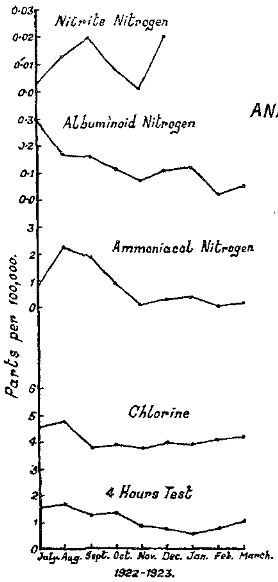
Head of analysis	*Crude sewage* 1	2	3	*Effluent* 1	2	3
Ammoniacal nitrogen ...	1·68	2·44	3·25	0·76	0·51	0·75
Albuminoid ,, ...	0·69	0·71	0·89	0·12	0·14	0·15
Nitrite ,, ...	nil	nil	nil	0·08	0·05	0·024
Nitrate ,, ...	nil	nil	nil	0·52	0·09	0·44
Oxygen absorbed from $KMnO_4$ in 4 hours ...	2·27	3·54	3·76	1·12	0·62	0·69
Chlorine	4·9	7·1	8·8	4·2	5·0	7 3

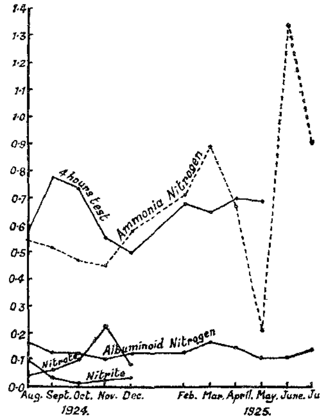
TABLE IV.

Average monthly analysis of sewage 1924–25: *parts per 100,000.*

Date	Amm. nitrogen	Alb. nitrogen	Oxygen absorbed in 4 hours
August, 1924 ...	1·75	0·93	2·34
September... ...	1·3	0 61	2·74
October	1·05	0·45	2 70
November... ...	1·83	0·66	1·89
December... ...	2·5	0·46	2·2
February, 1925 ...	2·55	0·64	3·06
March	2·17	0 40	3·35
April	2·53	1·02	4·40
May	2·50	0·68	3·70
June	2·39	0·62	...

Chart II.
Results of
ANALYSES OF EFFLUENT





The results indicate that the treated sewage is rather weak, compared with the standards of the Royal Commission and other tests; the effluent has been of a high degree of purity. Tests were made to note the period of detention of sewage in the tanks, and the collection of sewage and effluent was made at such times as to yield comparable samples. The percentage purification effected in relation to flow may also be noted. The average monthly analyses of effluent for 1922–23 and those of sewage and effluent for 1924–25 are given in Chart II and Table IV. Comparing the analytical figures obtained for Indian sewages with those found in Western countries brings out the difference in character and strength of sewage due to the different habits of the respective populations.

TABLE V.

Analysis of different sewages: parts per 100,000.

Origin	Suspended solids	Amm. nitrogen	Alb. nitrogen	Oxygen absorbed in 4 hours	Chlorine
Indian					
Indian Institute of Science ...	9	2·44	0·71	3·54	7·1
Kurseong (hill station) ...	42·4	...	...	6·5	10·4
Dacca	12·5	5·0	0·24	3·6	9·6
Matunga (Bombay)	31·8	1·08	1·62	...	3·36
Sibpur (Calcutta)	25·6	0·17	0·02	7·1	17·00
Jamshedpur (Bihar)	...	1·88	1·98	11·26	3·5
Madras	...	3·30	1·26	7·6	17·5
English					
Saltley	57·7	4·06	1·52	26·34	18·9
Reading	34·2	10·4	1·48	8·8	10·1
Tinsley	27·3	3 38	0·62	5·4	...
Sheffield	77·4	5·09	1·22	13·93	...
Davyhulme (Manchester) ...	17·8	2·32	0·76	7·21	10·8
Withington (Manchester) ...	...	2·23	0·67	3·76	4·4
American					
Milwaukee	25·9	1·56	0·89	12·5	19·4

One of the interesting observations made while operating the plant was that chemical analysis of the effluent gave some index to the biology of the sludge. The sludge, in August, 1923, and March, 1925, was found to 'bulk', increasing abnormally in volume and settling slowly. Microscopic examination revealed huge masses of filaments and a chemical analysis of the effluent gave the following figures:—

Analysis of effluent: August, 1923: parts per 100,000.

	1	2	3
Amm. Nitrogen	1·0	1·1	0·9
Alb. ,, ...	0·32	0·28	0·24
Nitrite ,, ...	Trace in 50 c.c.	Trace	Nil
Nitrate ,, ...	Nil	Nil	Nil
Total solids in 100 c.c. sludge	1·7 gm.	1·3 gm.	1·2 gm.

Analysis of sewage and effluent: March, 1925.

	Sewage				Effluent			
	1	2	3	4	1	2	3	4
Amm. nitrogen ...	2·2	2·1	2·5	1·87	1·98	1·05	1·8	1·08
Alb. ,, ...	0·42	0·48	0·44	0·16	0·26	0·24	0·11	0·12
Nitrite ,, ...	...	...	...	...	Nil	Trace	Trace	Nil
Nitrate ,, ...	...	...	...	...	Nil	Nil	Nil	Nil

It follows that purification in these circumstances was only 50 per cent. or less, due to the large masses of filament, much of which was suspended in the settlement tank and interfered with settlement.

Another point of importance noticed in varying the air-supply was that in spite of liberal aeration the dissolved oxygen-content of the final effluent never approached saturation, the highest figure being 0·3 parts per 100,000. Although Winkler's method indicated only very small quantities, in other respects the effluent was quite good. Incubation tests carried out on two different occasions with mixtures of effluent (10 per cent.) and aerated tap-water gave the following results.

Dissolved Oxygen in parts per 100,000.

Effluent			Aerated tap water	Effluent + Aerated tap water, c c.	
				0 hr.	120hrs.
I	...	nil	0·74	0·676	0 24
II	...	nil	0·69	0·621	0·14

These showed that the effluent was not putrefactive, as in such a case all the dissolved oxygen would have been used up within 24 or 48 hours. The presence of dissolved oxygen even after 120 hours' incubation proved that the effluent was of high purity. It was therefore considered probable that the microbiological forms in the sludge might be responsible for the low percentage of oxygen in the final effluent. Some experiments were therefore conducted in the laboratory on the following lines. Equal volumes of sewage were collected from the various aeration chambers, mixed and the mixture divided between two narrow-mouthed graduated cylinders and allowed to settle for an hour. The supernatant liquid from one cylinder was siphoned into a third cylinder and aerated comparatively with complete sewage for varying periods, when the dissolved oxygen in the clear liquid after one hour of settlement was determined in the usual manner. After 24 hours' aeration the dissolved oxygen in parts per 100,000 was as follows :—

Complete sewage	0·06	0·17	0·13	0·12	0·11
Supernatant liquid	0·39	0·56	0·55	0·65	0·33

The results show that the dissolved oxygen in the supernatant liquid is many times more than that in the complete sewage containing the sludge. Microscopic examination showed that the sludge was teeming with life, and with increased aeration large numbers of ciliated organisms developed. The effluent was free from any such kind of life. It is therefore quite probable that the living population of the sludge was using up the major portion of the oxygen injected into the tanks.

A measure of the oxygen up-take by the organisms was, therefore, made as follows. A sample of tap-water was aerated until saturated with oxygen and gently shaken with sludge until intimately mixed; after settlement for an hour, the dissolved oxygen was estimated in the supernatant liquid. The residual sludge was again gently shaken with aerated tap water and the dissolved oxygen once more estimated.

This operation was repeated many times on successive days and the following are the average results expressed in parts per 100,000, the dissolved oxygen in saturated tap-water being 0·69.

1	2	3	4	5
0·03	0·07	0·06	0·09	0·09

The results show that there seems to be no limit to the amount of oxygen taken up within the period of the experiments conducted.

Biological observations.

Microbiology of the sludge.—The bacterial and non-bacterial micro-organisms in activated sludge are varied and numerous. The bacterial population included the following types :—Ammonifying, nitrifying, denitrifying and nitrogen-fixing. These were demonstrated by inoculating suitable media and observing the several changes characteristic of the respective types.

The non-bacterial life ranged from minute protozoa to worms, insect larvae and insects. The following were among the more important forms recognised :—

1. Protozoa.—*Amœba Paramoecium*, *Vorticella*, *Stylorichia*, *Leucophrys*, *Cœnomorpha*, *Actinophrys* and *Acineta*.

2. Trochelminthes.—*Brachionus*, *Philodina* and *Distyla*.

3. Vermes.—*Dero* and *Auginllilla*.

4. Arthropoda.—*Diptera*, *Chironomus* and *Culex*.

Microscopic study showed whether the sludge was in condition or not, the presence of ciliated organisms being evidence of ample aeration while flagellate forms denoted defective air-supply. This is in accordance with the results obtained by Richards and Sawyer at Rothamsted (*J. Soc. Chem. Ind.*, 1922, 41, 62 T). Another result of defective aeration was the rapid development of *Chironomus* larvae and the appearance of the dero type of worms; occasionally culicine larvae could also be found.

The development of *Chironomus* larvae was important, being associated with an improper circulation of sludge in the aeration tanks. It was observed on two occasions that owing to low air-supply a portion of the sludge settled in some of the tanks. The *Chironomus* larvae were found to live at this low oxygen level and collected all the sludge particles into small cylindrical masses which were buoyed up to the surface of the liquid. The life history of this insect was carefully investigated. The eggs under the microscope resemble little strings of beads enclosed in a mucilaginous matrix attached to the walls of the tanks. The larvae emerge from the eggs in less than 48 hours, are blood-red in colour, 10–15 mm. long and segmented. They possess bristly projections at both ends, swim with a wriggling, lashing motion and live in tubes made of the sludge particles. Millions of these larvae may accumulate and collect a large proportion of the sludge, which either floats or becomes firmly attached to the walls. The larva developed into the pupa, the pupa into the imago and this into the chrysalis, the complete life cycle being repeated in the tanks. Only the larval stage of the above insect gives trouble, and the other stages of its life did not affect the sludge. Vigorous agitation in the early stages prevented the sludge from settling: the larvae then found it difficult to develop, and consequently no trouble arose. They were very susceptible to the action of kerosine and the briskly moving larvae were at once destroyed by this means, losing their red colour and rising to the surface.

Seasonal variations of the different types were remarkable. *Amœbæ*, *Stylonichia*, *Leucophrys* and *Nematodes* were invariably noticed in the sludge from October to March. *Paramoecia* and *Rotifera* were observed to be more numerous from July to October though they were found throughout the year. *Vorticella* and *Acineta* developed very rapidly with ample air-supply and appeared in all seasons. The *Chironomus* insect and the dero worms appeared chiefly from August to November, although now and then a few could be recognised at other times. With low air-supply and 'bulked' sludge culicine larvae could always be found.

Apart from the appearance of non-bacterial life in the sludge, a study of the relationship between the higher forms and the bacteria present was of profound interest. From continued observations under the microscope it is believed that a major proportion of these higher organisms used the bacteria in the sludge as their food supply. *Vorticella* and *Rotifer* are two examples in which it is easy to see that this process takes place. Both organisms are microscopic, and reveal cilia with which they direct the sludge particles, and probably countless bacteria also into their mouths. To study this relationship, work similar to that of Fairbrother and Renshaw (*J. Soc. Chem. Ind.*, 1922, **41**, 134 T) was conducted. The researches of Russell and others have shown that, in the case of soils, if partial sterilisation is effected either by heating to 100°, or by treatment with volatile antiseptics which are subsequently removed, there is a marked increase in the amount of oxygen absorbed by the micro-organisms of the soil (*J. Agric. Sci.*, 1907, **2**, 305). Goodey also has shown that soil protozoa exert a depressing effect on the soil bacteria (*Proc. Roy. Soc.*, 1917, **89 B**, 297). Fairbrother and Renshaw state that 'in the case of sewage purification the method which is most economical, least noxious, most rapid and which gives highest fixed nitrogen content in the sediment is the activated sludge process. This process appears to be checked from time to time with the coincident growth of zoological masses and *Paramoecia* which use as food the bacteria causing the purification. Treatment of the tanks by this group of dyes (triphenylmethane) should result in elimination of the protozoa without disturbance to the bacteria'. In the present experiments therefore the sterilising agent consisted of Meldola's blue, or New blue R; Acridine yellow; Methylene blue.

Each dye solution was prepared by dissolving one gram in 100 c. c. of distilled water. To estimate the antiseptic action, a hanging drop preparation of the sludge was made on a cover-slip and examined under the microscope in a Botcher's chamber. The organisms were noted and an equal quantity of the stock dye solution added to produce a 1/200 dilution, and the suspension again examined under the microscope. If the organisms were dead, the dye solution was diluted and the effect tried as before with greater dilutions. The procedure adopted was exactly similar to that of the previous workers. The following results were obtained :—

Dye.	Dilution						
	1/200	1/500	1/1000	1/2000	1/5000	1/10000	1/20000
Methylene blue	All organisms except *Chironomus* and *Dero* are killed; these are stained.	...	Protozoa killed; Rotifers stained but unaffected.	Protozoa killed.	Protozoa alive.	Protozoa alive.	Protozoa alive.
Acridine yellow.	,,	...		Protozoa killed; Rotifers unaffected but stained.	Protozoa killed.	,,	,,
Meldola's blue.	*All* paralysed ...	*Chironomus* and *Dero* stained but not killed.	,,	,,	,,	Protozoa killed.	,,

The highest dilution of each dye effective in killing the protozoal forms was therefore :—Methylene blue, 1/2000; Acridine yellow 1/5000; Meldola's blue, 1/10000. Quantities of the sludges after treatment with dyes were then plated out on nutrient agar in Petri-dishes, dilutions being made in the usual manner, undyed controls being kept. The following counts were obtained:—

TABLE VI.

Influence of protozoa on bacterial numbers (1000's).

A		B		C	
Sludge and Meldola's blue	Sludge only	Sludge and methylene blue	Sludge only	Sludge and Acridine yellow	Sludge only
25	3	5	3	10	25
11	5	6	5	6	2
140	100	11	3	200	80
9	3	70	25	50	8
23	65	43	65	60	20
200	25	57	25	...	...
70	37	11	3	...	...
45	30	...	...	...	...
33	50	...	...	...	...
40	1,500	...	...	...	...
17	12	...	...	...	...
100	470	...	...	...	...
750	1,500	...	...	...	...

The above table clearly shows that when protozoa are inhibited, bacteria increase. In Nos. 9, 12 and 13, however. the total counts in the sludge without dye were the greater; these were all 'bulked' sludges, containing masses of the filamentous organism with few protozoa. Richards and Sawyer have obtained similar results (*J. Soc. Chem. Ind.*, 1922, **41**, 627) working with volatile antiseptics.

Experiments were made to ascertain also whether the absence of the protozoa accelerates nitrification. In three Erlenmeyer flasks of 100 c. c. capacity 50 c. c. of Winogradski's medium containing potassium hydrogen sulphate, magnesium sulphate and sodium chloride with a trace of calcium chloride were introduced, and sterilised in an autoclave at 10 lbs. pressure for 15 minutes. One gram of sterilised magnesium carbonate and 2 c. c. of a two per cent. solution of ammonium sulphate were added to each; one was kept as a control, the second inoculated with a small quantity of the treated sludge, while the third flask was inoculated with untreated sludge. All were incubated at 37° and examined for nitrites and nitrates once in two days. Nitrification proceeded so rapidly in the second and third flasks that within a week 0·1 part per 100,000 of nitrates could be estimated in each, while the control did not show any trace of nitrite or nitrate; after three weeks only traces of ammonia were present. No appreciable difference in action of the treated and untreated sludges could be noticed. The experiments showed that inhibition of the protozoa did not induce more rapid nitrification.

Bulking.—That a low air-supply to activated sludge tanks also affects the biology of the sludge was shown by the phenomenon of 'bulking' already described. The volume of sludge then found in the aeration tanks suddenly becomes abnormal and increases with considerable rapidity during several days. The sludge also changed in physical character, was slow in settling, with less than 50 per cent. purification and the effluent contained a large quantity of suspended solids.

A microscopic examination revealed the immediate cause of bulking to be large masses of filamentous growths while higher forms of life were rare (nil in 0·01 c. c.). Sludge in the aeration tanks was measured by collecting equal samples, allowing settlement for an hour and reading the sludge level. Generally speaking, the amount built up in a day ranged from 2 to 5 per cent., but during the bulking period the percentage of sludge increased from 25 to 40 per cent. in two days and subsequently to 60 per cent., this percentage being maintained for a week. The sludge was grey and did not resemble a normal, healthy sludge. When allowed to settle, there appeared a white slimy mass above the sludge proper. The latter never settled quickly and the supernatant liquid always had in suspension some white flecks which appeared in the effluent also.

The filaments were straight rods of varying lengths enclosed in a membranous sheath. A culture of the organism was made on nutrient agar as well as on several sugar media. The multiplication was very vigorous and good growths were obtained within 18 hours. The organism is gram-positive, does not produce acid or gas and does not thrive in even slightly acid media. A drop of dilute acid added to the effluent flocculates these filaments, which appear to grow better in liquid cultures than on solid media. In the former case the sheath is preserved, while in the latter it is lost and the thread-like form disappears. The filaments on two occasions were found to be the cause of bulking, while protozoa, which have been stated to be the cause, were found throughout the year with low or high air-supply without giving any trouble.

The filaments are probably *Sphærotilus natans* or a closely related organism. *Sphærotilus natans* has been described as a sewage organism by several workers, but although its various characteristics have been described, its functions do not seem to have been fully studied. According to Ohlmuller and Spitta (*Wasser und Abwasser*, 180) it is found in shallow, flowing water in the form of whitish flakes and skin-like incrustations. Its appearance is favoured by sewage or cellulose factory wastes and it is found in sugar refineries and brewery effluents. It consists of a series of cells enclosed in a sheath and forms in this manner thin threads of about 2μ diameter. *Sphærotilus* is found everywhere and is the most characteristic of drainage organisms. Similar descriptions are given by many other workers, e.g., Thresh, Bergey, David Ellis and Mrs. Mumford.

Whenever the sludge bulked, the only remedy was to reduce the flow of sewage and increase the supply of air for a prolonged period when the filaments rapidly broke up and were thus destroyed (O'Shaughnessy, *J. Soc. Chem. Ind.*, 1923, **42**, 359T).

Experiments on de-watering of activated sludge.—One of the difficulties encountered in this method of sewage treatment has been the disposal of the surplus sludge. Where large areas of land are available, no difficulty arises in the disposal; otherwise, a method of de-watering has to be adopted. Activated sludge retains water so tenaciously that de-watering presents a real problem which has not yet been solved; this remains the one weak point of the method, which in other respects has given most excellent results.

The volume of sludge pumped from the plant in question is between 3,000 and 4,000 gallons per week. The water-content is normally 97 to 97.5 per cent., but rose to 99 per cent. when the sludge bulked. All is pumped to a compost-pit where the sludge is de-watered and fermented to a valuable fertiliser.

De-watering experiments on a laboratory scale were conducted on the lines of Wilson and Heisig (*J. Ind. Eng. Chem.*, 1921, **13**, 406). Definite volumes of sludge, say, 100 c.c., were treated with varying amounts of N/2 sulphuric acid or aluminium sulphate solution, the mixture being then thoroughly stirred, poured on to Buchner funnels and filtered by suction through paper. The time taken for the sludge to filter, until free from visible moisture, was noted by a stop-watch and the P_H of the filtrate determined colorimetrically; the filtered solids were weighed at once and after drying at 105°. The results are recorded below.

TABLE VII.

Experiments with N/2 Sulphuric Acid (100 c.c. of sludge).

Acid c.c	Time for filtration		Filtrate P_H	Percentage moisture in filter-cake
	Mins.	Secs.		
0	10	...	7·2	30·5
1	9	51	6·6	30·0
2	8	35	5·8	29·0
4	6	8	5·2	26·5
5	4	21	3·6	21·5
10	1	30	2·6	16·7
15	2	...	1·6	22·0

TABLE VIII.

Experiments with N aluminium sulphate (100 c.c. of sludge).

Alum c.c.	Time for filtration		Filtrate P_H	Percentage moisture in filter-cake
	Mins.	Secs.		
0	10	...	7·2	30·5
0·5	1	35	7	29·5
1	0	52	6·2	29·0
2	0	33	5·2	23·7
5	0	40	4·7	26·5
10	1	...	3·8	24·5

From this it is clear that in the case of sulphuric acid filtration was quickest at a P_H of 2·6, when the moisture was also the lowest. Either above or below this range of P_H, the moisture-content increased as well as the time taken for filtration. Addition of acid produced bubbles of gas and the colour changed from brown to yellow. Addition of alum produced a porous filter-cake which could not maintain a vacuum of more than 30 c.m., and a sharp minimum was attained at P_H 5·2. It produced a turbidity in the supernatant liquid, otherwise there was no change. The moist filter-cake in neither case produced any smell when exposed for 3 days.

De-watering was also tried on a small scale by centrifuging 50 c.c. at a time at 2,500 to 4,000 r.p.m. for 10 minutes. The moisture-content of the resultant sludge was still 40·8 per cent. however. Experiments in drying on sand and turf beds have also given fairly satisfactory results. Sludge on a turf bed dried more slowly than on a sand bed, but while in the latter case the sludge became incorporated with the sand, the former gave a cake yielding to the spade. The dried products, even after storage for many months, gave no offensive smell. On the whole, treatment with alum appears the most promising line of attack. Analyses of dried sludge are given in table IX.

TABLE IX.

Analysis of air-dried activated sludge (per cent.).

	1	2	3	4	5	6	7	8
Moisture ...	7·94	8·12	8·1	8·14	...	...	...	..
Organic matter ...	66·00	69·4	64·4	70·2	69·6	67·0	74·41	75·51
Total nitrogen ...	3·33	4·0	4·69	5·0	4·94	4·95	5·01	5·02
Phosphate as P_2O_5 ...	...	...	...	2·3	...	...	2·89	3·24
Potash as K_2O ...	...	...	...	0·5	...	...	...	0·88

Elasticity of the process.—Although the plant was intended to treat 6,000 gallons of sewage per day, actual experience has shown that it is able to work on either side of this figure to a considerable extent. Laboratory experiments have also shown that activated sludge can become acclimatised to treat trade-effluents with success. The writer was able to secure quantities of creamery and tannery-wastes, and treatment of these liquors by activated sludge was eminently successful. In both cases the waste liquors were foul, but, by inoculating them with 20 per cent. activated sludge and aerating for two days, an odourless, innocuous liquid was obtained, colourless from creamery-waste and still coloured from tannery-waste. The process seems to be very sensitive to acid, but if this is neutralised the sludge begins to function. Sludges were treated with sulphuric acid and aerated for a number of days without producing any effect, but immediately after neutralisation the activity was restored. The nitrifying organisms seem to function best between P_H 7 and 8, although they thrive well between 5·8 and 8.

Economics of the process.

The Capital cost of the plant was as follows :—

	Rs.
Constructional work	4,969
Equipment from Messrs. Activated Sludge, Ltd.	5,064
Reavell Compressor	400
Scott ,, (approx.)	700
3 h.p. Motor and cable	592
5 h.p. Motor	453
3 Zinc sheds for motor and compressor	397
Grates, plate covers, etc.	88
Total	12,663

Maintenance cost per annum :—

	Rs.
Interest at 6 per cent. per annum	760
Depreciation at 12 per cent. per annum	258
Power consumption, 62 units per day, at 6 pies per unit	707
Chemist in charge	840
Watchmen	372
Lubricating oil, cotton waste, etc.	66
Total	3,003

On the above basis the capital cost is Rs. 33-12-0 per head of population (375), or Rs. 5-10-0 per 1,000 gallons treated, assuming 6,000 gallons per day, yearly. The maintenance costs are Rs. 8 per head per annum, or Rs. 1-6-0 per 1,000 gallons treated. For a larger plant these rates would be very materially reduced.

Summary and conclusions.

The plant has been in operation continuously for a period of more than four years except for a few days from time to time owing to failure of current and other circumstances. The plant had to be re-started on two occasions when the rate at which nitrification was established and the building up of sludge have been much more rapid than on the previous occasion. A plant of this type appears to possess the following advantages :—

1. The sewage may be purified to any desired extent.

2. The space occupied by the plant is only about one-third that required by a closed septic tank and bacteria-bed, or any other form of sewage-treatment plant.

3. The treatment yields a sludge which contains a high percentage of nitrogen and is therefore valuable as a fertiliser.

4. Maintenance costs are low, as an ordinary workman trained for the purpose can control the plant with occasional expert advice.

Low air-supply tends to produce bulking and the development of numerous insect larvae and worms. Ample aeration obviates the above troubles and restores order. No trouble with the diffusers has arisen except occasionally when a large quantity of silt has been deposited, removed by steaming.

The average effluent has been quite satisfactory; although nitrates were present in large quantities, the dissolved oxygen has always been very low.

The biological forms in the tanks have shown a seasonal variation and the presence of filamentous growths always contributed to an unhealthy and bulked sludge. There seems to be a relation between the protozoal and the bacterial numbers, the former tending to keep down the latter.

Though no necessity for de-watering the sludge has arisen, the experiments show that after suitable treatment the sludge can be rapidly filtered, yielding a filter-cake with a comparatively low moisture-content.

In conclusion, I am glad to acknowledge my indebtedness to Professors Gilbert J. Fowler and R. V. Norris for their keen interest in the work and for their continued guidance throughout the course of this investigation.

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[Accepted, 13-6-29.]