THE ACTIVATED-SLUDGE METHOD OF SEWAGE PURIFICATION

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PURIFICATION OF SEWAGE BY ACTIVATED SLUDGE IN WINTER AT THE SEWAGE TESTING STATION, MILWAUKEE, WISCONSIN

By W. R. COPELAND

Chief Chemist, Milwaukee Sewage Testing Station

In winter the temperature of the Milwaukee sewage averages about 51° F. with occasional drops to 40° F. or less when melted snow enters the sewers. These low temperatures, especially the latter, retard oxidation of organic matter and decrease the stability of the treated liquor. By applying 2¼ cu. ft. of air per gallon of sewage the continuous-flow plants removed 90 per cent of the bacteria in the sewage of Milwaukee and reduced the suspended matter to about 15 parts per million. The sludge contained about 5 per cent of nitrogen calculated as ammonia, 1¾ per cent of available phosphoric acid, and 0.4 per cent of potash. This sludge can be recovered by pressing without the use of lime.

The sewage testing station of Milwaukee, on the shore of Lake Michigan, is exposed to the full rigor of this northern climate. During January and February the thermometer registered below zero on nine days and dropped to -15° at the coldest period. The sewage temperature dropped with the approach of winter from 67° F. in September to 50° F. in January, but

sewage purification have maintained for years that quantities of material valuable for fertilizer were being wasted by dumping the sewage of Milwaukee into Lake Michigan. The great problem connected with the recovery of these products lies in separating the sludge from the water. The activated sludge contains 98 per cent of water and 2 per cent of suspended solids and some of the solids seem to be sticky. Centrifuges or presses of the usual patterns heretofore employed have proved unsatisfactory either because the cloths used as strainers became choked with the gluey matters or because considerable quantities of lime had to be added to give enough body to the liquor for the presses to work on. The lime added attacked the nitrogen compounds, driving off ammonia, and combined with the fats to form insoluble soaps. Such treatment decreased the value of the sludge and by building up the volume increased the cost of removal. The Henry R. Worthington Co. installed a new type of press at the Milwaukee sewage testing station that has treated the activated sludge with marked success. No lime is required, the bags do not get sticky, comparatively little power is used, and the sludge obtained can be converted into fertilizer. Typical analysis of activated sludge re-aerated and of pressed sludge cake are given in Table II.

Some characteristic samples of the sludge that were sent to

TABLE I—AVERAGE DAILY ANALYSIS OF SEWAGE BEFORE AND AFTER PURIFICATION BY THE MILWAUKEE CONTINUOUS-FLOW ACTIVATED-SLUDGE PROCESS AT FALL AND WINTER TEMPERATURES: SOURCE OF SAMPLES—SEWAGE AND EFFLUENT

Month and Year	TEMPERATURE ° F.		Sewage Treated Gal.	AIR PER GAL. Cu. ft.	BACTERIA PER CC.		Stability Hours	P. P. M. NITROGEN AS					P. P. M. OXYGEN	
	Air	Liquor			20° C.	37° C.		Suspended Matter P. P. M.	Free NH ₃	Organic	Nitrite	Nitrate	Consumed	Dissolved
Oct., 1915.....	53	62	59,000	1.6	1,384,000	347,000	...	263	17.0	38	0.21	0.10	127	1.5
		63			56,000	12,000	120	16	5.1	9	0.22	8.70	19	2.8
Nov., 1915.....	41	59	60,000	2.1	1,242,000	297,000	...	438	17.5	40	0.16	0.20	149	2.3
		61			119,000	12,000	120	16	11.4	17	1.09	4.10	27	6.3
Jan., 1916.....	27	50	71,000	1.7	770,000	170,000	...	336	15.4	35	0.13	0.51	135	5.5
		49			62,000	8,800	88	11	14.7	19	0.16	0.67	31	6.1
Feb., 1916.....	22	51	68,000	2.1	960,000	150,000	...	300	17.2	42	0.16	0.36	143	4.8
		50			68,000	8,000	96	14	16.5	22	0.17	0.50	27	6.4
Mar., 1916.....	37	50	71,000	2.3	1,000,000	126,000	...	383	15.8	36	0.13	0.41	146	4.7
		50			159,000	16,000	67	15	15.2	21	0.19	0.42	35	6.0

the zero weather did not reduce it further. When melting snow water entered, however, the temperature of the sewage dropped for several hours at a time to 43° F. and on a few occasions registered only 34° F. As the oxidation of organic matter obtained with the activated sludge process depends upon the activity of living bacteria which do their best work at 68° F. to 70° F., we looked forward with some misgiving to the winter period because their vitality would be checked by the cold sewage. But by increasing the air supply the plants were enabled to remove the suspended matter, colloids, and bacteria in a satisfactory manner as indicated by the analyses given in Table I. The data show that as the temperature of the sewage dropped the oxidation of the organic matter decreased, as indicated by the fact that nitrate in the effluent fell from 8.7 in October to 0.67 part per million in January, and the oxygen consumed increased from 19 to 31. The decrease in oxidation was accompanied by a decrease in stability of the effluent from 5 to 3 days. The treated liquor contained 6 parts per million of dissolved oxygen in January, February, and March and only a trace of nitrate, whereas in summer nitrate is high and dissolved oxygen is low; therefore, the liquor seems to depend for its stability on nitrates in summer and dissolved oxygen in winter. Briefly, the data show that good bacterial removal and clarification can be maintained at winter temperatures without oxidizing the ammoniacal nitrogen into nitrate.

Bearing in mind that quantities of fat, nitrogen, and perhaps phosphoric acid are turned into the sewers daily by the houses, breweries, packing houses, tanneries, etc., men interested in

other laboratories for analysis contained about 0.43 per cent of potash.

From the data obtained at the Milwaukee sewage testing station it appears that the activated sludge process will yield about 3000 or 4000 gallons of sludge containing 98 per cent of water per 1,000,000 gallons of sewage treated. When reduced to 10 per cent of moisture this sludge will weigh about one-half ton. Assuming that the nitrogen is worth \$2.00 per unit, the value of the sludge should range between \$10.00 and \$12.00 a ton. We estimate that it will cost \$5.00 to \$6.00 to convert the sludge into fertilizer and pay freight to the consumer.

The data in Table I show that the suspended matter in the Milwaukee sewage received at the station is rather high, perhaps one-third to one-half greater than that of average American

TABLE II—AVERAGE ANALYSIS OF REAERATED ACTIVATED SLUDGE AND PRESS CAKE

SOURCE	Sp. gr.	Mois- TURE	PER CENT BY WEIGHT—BASIS 10% MOISTURE		NITROGEN					TOTAL
			SOLIDS	Min- eral	Or- ganic	FAT	Free NH ₃	Albun. NH ₃	Ni- trate	P ₂ O ₅
Sludge...	1.004	98.9	32.5	57.3	5.8	5.6	1.17	3.19	0.30	2.3
Cake...	1.113	74.6	30.2	59.9	4.3	6.3	0.59	2.82	0.12	1.88

(a) The figures are for nitrogen calculated as "Free Ammonia" and were obtained on sludge which had been stored with continuous aeration for several days, and they are about 1 per cent higher than those that would be obtained by pressing fresh sludge.

sewage. For that reason the volume of the sludge recovered here may be greater than would develop in cities where water is used more extravagantly.

Experiments on purification of sewage by the activated-sludge

process in winter have therefore shown that about 90 per cent of suspended matter and bacteria were removed, that the sludge can be dried by pressing from 98 to 75 per cent moisture, thereby converting the sludge into a small volume which can be easily handled, and that the sludge has sufficient value to ensure a constant market.

MILWAUKEE, WISCONSIN

AERATION OF SEWAGE IN THE PRESENCE OF ACTIVATED SLUDGE

By E. J. FORT

Chief Engineer of Sewers, Borough of Brooklyn

The engineering profession for a number of years has been looking for a method of sewage treatment based on biological and biochemical principles and employing air under pressure applied directly to the sewage. The advantages that such a method promises of very intensive treatment with relatively small expense for land and elimination of extensive filter beds and the entire septic cycle, thus doing away with the offensive odors that evolve from the putrefaction of sewage and sludge, have rendered it a very attractive subject for investigation and experiment. Until recently the results of many investigations and studies have been little more than suggestive of unrealized possibilities.

The experiments of Black and Phelps at the Brooklyn Sewage Disposal Plant in 1910 were about the first that indicated the possibility that there had been discovered a method of treatment with compressed air, which might on further study and development prove to be the one sought so long. These experimenters found it possible to reduce the demand of sewage for oxygen 33 to 50 per cent in a retention period of about three hours by using about two volumes of air per volume of sewage. As the scale on which these experiments were made was small and the apparatus was rather crude a more thorough investigation obviously was necessary before their results and the principles could be utilized in designing and operating full-sized plants.

In 1912, sewage-treatment experiments were authorized by the City of New York on a rather liberal scale, and several units were provided in the design of the experimental plant to carry on studies of sewage aeration. A 16,000-gal. tank arranged for aeration experiments and named the tank aerator, the design of which met the approval of Professor Phelps, was put in service in the fall of 1913 as a continuously flowing sewage aerator. This tank was so connected to the system that it could be operated either by the continuous flow or by the fill-and-draw method and could be supplied either with crude sewage or with the effluent from Imhoff tanks. Sewage was introduced at the top and withdrawn from the bottom, though this method of operation could easily be reversed by a slight change of pipe. The crude sewage was supplied by gravity from the sewage supply, or quieting tank, that served the entire experimental work of the station. It was pumped from the sewer by a reciprocating pump and was detained less than five minutes in the quieting tank. Compressed air was supplied by a duplex air compressor of ample size, installed as part of the experimental plant.

The tank was 12 ft. in diameter and 25 ft. 8 in. in depth. A grid for supplying compressed air, which was placed at the bottom of the tank, was supported by $7\frac{1}{2}$ in. of broken stone which passed a 2-in. but was retained by a 1-in. ring. An equal depth of broken stone of the same size was placed over the grid, so that the air first passed upward through the voids in the broken stone. The outlet of the tank, as originally installed for sewage-aeration experiments, was about one foot above the surface of the broken stone, so that one-twentieth to one-twelfth of the contents of the tank was retained at each emptying. A lower outlet was provided for draining the lowest level of the tank. The compressed-air grid consisted of two $1\frac{1}{2}$ -in. pipes crossed at right angles in the center. The arms of the cross

were connected with quarter circles of $\frac{3}{4}$ -in. pipe to form five concentric rings, each of which was perforated at 6-in. intervals with $\frac{1}{16}$ -in. holes. The air, entering through $1\frac{1}{2}$ -in. pipes, was thus distributed to the rings and discharged into the broken stone surrounding the grid.

Nine deflector discs, supported by a vertical 4-in. pipe in the center of the tank, formed a feature of the tank. The discs were in form not unlike wheels; the supporting pipe passed through their hubs. The surface of each disc was horizontal, and occupied the entire cross-section of the tank, which was thus divided into story-like compartments. They were designed to deflect the downward flow of sewage in order to prevent downward streaming and to equalize and give a sinuous motion to the upward flow of air; thus more even distribution of both air and sewage were secured. As stated above they were each made in the form of a wheel, supported on six arms, between which were slats, radiated from the iron hub of each disc. The slats were set in grooves in the arms with a dip of 45° . The slats in alternate discs were set sloping from and toward the center.

The first experiments, in 1913, on the continuous-flow plan with plain aeration of sewage in the tank aerator, were made with an air supply of 0.75 volume per volume of sewage and 2-hr. retention period. This it was considered would be the minimum treatment. It was insufficient to produce any marked result. The retention period was, therefore, doubled, but with little improvement. A greater volume of air was then applied but the result was not satisfactory, and the results secured were not even promising during the winter and early spring of 1914. As it was thought that the tank would work better after it had been thoroughly seeded with aerobic bacteria, the continuous-flow method was suspended, and the sewage was retained in the tank under aeration for 24-hr. periods, the fill-and-draw method of operation being followed. Some phenomena of activated sludge were observed at this stage of the experiment, but the principle was not then recognized as being important. This method of ripening was carried on until June 14, when apparently the tank had ripened, and a fine clear effluent could be obtained with certainty from crude sewage or Imhoff tank effluent on the fill-and-draw plan with 24 hrs. aeration.

Return was then made to the continuous-flow method, and operation was commenced with 3.25 volumes of air per volume of sewage with 5-hr. tank retention. This did not produce an effluent of satisfactory stability. The retention period was increased to 24 hrs., with the same rate of air flow per minute, the air supply being thus increased to 18 volumes per volume of sewage. The effluent after passing a settling tank with 3-hr. retention then showed a quality comparable with that from a sprinkling filter. Its average relative stability was 84 per cent. The quantity of air was later reduced one-half, or to 9 volumes per volume of sewage treated, the continuous-flow plan being retained. Under these conditions the relative stability of the settled effluent fell to 59 per cent. This work was continued until it seemed to be demonstrated completely that though a fairly satisfactory effluent could be obtained the cost of air made the treatment considerably more expensive than treatment by the sprinkling filter.

Table I shows the average of results of operating the tank aerator to October 1, 1914, on the continuous-flow plan without the employment of activated sludge. Of course, some activated sludge may have been present, but if so it was not recognized as such, and we had then no knowledge of that method, which was not announced until this series of experiments was about completed.

As experiments in sewage aeration with activated sludge characterized our work during 1915, the aerator tank was rearranged in March for use as an activated-sludge tank. The accumulation of activated sludge, which had been commenced about the middle of March, was sufficient to permit regular