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 7½ 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 1½-in. pipes crossed at right angles in the center. The arms of the cross

were connected with quarter circles of ¾-in. pipe to form five concentric rings, each of which was perforated at 6-in. intervals with 1/16-in. holes. The air, entering through 1½-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

operation of the experimental unit by the middle of May, but it was thought best to continue until June 1st, on which date the tank was put into service on a regular cycle of operation. The cycle began with a period of sedimentation, during which the air was shut off, followed by a period of discharge, which con-

TABLE I—RESULTS OF OPERATING TANK AERATOR ON CONTINUOUS-FLOW PLAN WITHOUT ACTIVATED SLUDGE

[Parts per Million Except as Otherwise Designated]
Period of retention in tank aerator, 24 hours. Amount of crude sewage treated in 24 hours, 16,000 gallons. Air applied, 2.3 cu. ft. per gallon. Settlement period of effluent in settling tank No. 1, 3 hrs. 12 min.

	Crude sewage	Tank aerator	Settling Tank No. 1
Settling matter (cc. per liter).....	2.3	5.4	0.2
Total suspended solids.....	164	103	40
Volatile suspended solids.....	130	79	30
Total oxygen consumed.....	58	39	26
Dissolved oxygen consumed.....	37	27	22
Total dissolved oxygen.....	1.4	3.1	1.1
Dissolved oxygen demand.....	191	55	31
Relative stability (percentage).....	..	..	..
Undiluted.....	2	43	84
Diluted 1:10 with distd. water.....	35	94	100

tinued 1½ hrs., when refilling began and the air was turned on. Refilling continued for 1½ hrs., and aeration was continued for a period of 20 hrs., when the cycle began again. The air was measured by a Venturi meter devised for the purpose. Both influent and effluent sewage were measured. The results in averages for June, July and August, 1915, are shown in Table II.

TABLE II—RESULTS OF SEWAGE AERATION IN PRESENCE OF ACTIVATED SLUDGE ON FILL-AND-DRAW PLAN
[Parts per Million]

DETERMINATION	MONTH	HOURS AFTER REFILL			
		Crude sewage	0	2	5
Suspended solids.....	June	180	35	24	20
	July	147	21	12	9
	August	154	24	12	8
Dissolved oxygen.....	June	1.0	0.0	0.1	0.4
	July	0.7	0.0	0.0	0.2
	August	0.5	0.0	0.0	0.1
Relative stability.....	June	..	14	31	76
	July	..	11	34	84
	August	..	12	28	63
Oxygen demand.....	June	230	53	38	..
	July	173	63	38	..
	August	211	53	34	..
Nitrite.....	June	..	0.08	0.11	0.49
	July	..	0.01	0.07	0.25
	August	..	0.00	0.07	0.12
Nitrate.....	June	..	0.10	0.60	1.20
	July	..	0.00	0.25	1.57
	August	..	0.00	0.10	0.53
Volumes of air per volume of sewage		..	1.17	3.50	7.00

It will be observed that a very good effluent was obtained on the fill-and-draw method of operation after 5 hrs.' aeration with 7 volumes of air per volume of sewage. This may be compared with the work of the tank aerator in 1914 under the continuous-flow method without activated sludge, with 9 volumes of air and 24 hrs.' retention; and also with 18 volumes of air in the same period.

The following extract from our laboratory record is of interest:

"The rapidity with which the organisms present reduce the demand for oxygen is noteworthy. During the process of refilling, the demand falls from about 200 parts per million on the average to about 60 parts per million. Part of this drop is, of course, due to dilution with purified liquid from the previous run which remains with the sludge in the part of the tank below the draw-off pipe. Dilution, however, would reduce the demand only to 10/10 of its original value, or to 123 parts per million. This demand of 63 parts (123 — 60) is satisfied by the nitrite and nitrate oxygen, which is also reduced much more than the dilution would account for, in addition to the atmospheric oxygen dissolved from the air blown through the tank. This 63 parts is seen to be about seven complete saturations at summer temperatures. Bartow and Mohlman¹ call attention to the effect of nitrite and nitrate oxygen from the previous cycle in aiding the stability of sewage in the early stages of treatment.

"The rate of fall of demand constantly diminishes throughout the cycle, thus conforming to what seems to be a general law of all purification processes, namely, that the action proceeds most rapidly at the start. This seems to indicate that there is proportionally a large volume of the less resistant matter present, which having high avidity for oxygen is attacked promptly, and that as the process continues the more resistant matter becomes a large proportion of the whole. It may indicate that a given amount of air would be most advantageously utilized

¹ THIS JOURNAL, 7 (1915), 318.

by blowing it very rapidly at the beginning and less rapidly as the treatment proceeds.

"A drop in efficiency is noticeable during August in all points under observation. This is very possibly due to accumulations of sludge in the bottom of the tank which are not lifted by the air and consequently interfere with nitrification. The presence of the deflectors makes direct observation of this point impossible without interruption of the experiment, but indirect evidence supports this theory.

"The phenomena attending the sedimentation of well-activated sludge are very interesting. When the quantity is considerable (about 20 per cent at complete subsidence) the behavior in a settling cylinder is much the same as that of the precipitate resulting from the addition of manganous sulfate and alkaline iodide to water in the determination of dissolved oxygen. The material subsides as if it were a mass of loose cotton undergoing compression, with a sharp line of demarcation between the suspensa and the supernatant, and not like an aggregation of free falling particles with widely varying rates of subsidence, giving rise to a shading off into clear supernatant. The initial rate of settling in a test recently made was a trifle over an inch per minute, which rate rapidly diminished as the process of compacting went forward."

Experiments were also successfully made with a continuous-flow activated-sludge aerator tank, but these have not yet been fully completed, and further work will be done this summer. In economy of operation the results so far obtained are fully equal to those obtained by the fill-and-draw method. One of the main drawbacks of the process seems to be its unreliability or the tendency toward deterioration of the effluent as treatment continues unless constant vigilance is exercised.

The problems met in the operation of a full-sized sewage-treatment plant are not identical with those in an experimental laboratory. The vast mass of sewage to be treated cannot be handled in a full-sized plant with the exactness and facility afforded in experimental work. Our main object in designing sewage treatment works (from an engineering standpoint) is to provide methods of treatment that shall at all times afford satisfactory effluents for discharge into local waters. An effluent need not necessarily be clear and sparkling, nor need it be of a higher degree of stability than is locally required, but it must always be satisfactory and never subject to such deterioration that the plant provided may for a time fail from any cause against which provision can be made.

The plant that will give the most certain result under all local and general conditions of practical care with the ordinary risk of carelessness considered must, of course, commend itself to the engineer responsible for the work. Explanations and excuses do not produce results or absolve the designer for taking chances with methods that have not proved entirely reliable. The attitude of the designer must necessarily differ from that of the experimenter. At the same time, though these considerations in all their force may be admitted, the attitude of the engineer ought not to be so conservative that his employer may lose the advantage of any real advance.

We must not lose sight of the facts that a sewage-disposal plant when it is put into service is intended to be operated continuously at the efficiency for which it was designed, and that a constantly increasing burden will probably be put on it in consequence of rapidly increasing service and inefficient management. The scientist may design a plant to meet the requirements of a certain standard of service and up-keep, but the politician at once comes on the scene and dictates by whom the plant operation shall be directed and what supplies and repairs shall be provided for it in the annual budget. If the plant as designed and installed requires the watchful care of a scientist and daily supervision by a sewage expert to make it give satisfactory service with reasonable certainty it will have no place in the ordinary American city while our governmental institutions are what they generally are; moreover, if the plant is small, the cost of operation will be greatly increased by the expense of providing scientific management. Everything considered, therefore, the con-

clusion seems to me to be justified that, so far as we have gone and, as far as I can learn, so far as others have gone with this process, its excessive cost and sensitiveness or lack of reliability are such that the engineer is not warranted in recommending it for general adoption except where special conditions control.

1013 MECHANICS BANK BUILDING
BROOKLYN, NEW YORK

ACTIVATED-SLUDGE EXPERIMENTS AT THE SEWAGE DISPOSAL PLANT, BALTIMORE

By CALVIN W. HENDRICK

Chief Engineer, Department of Public Improvement, Baltimore

Work on activated-sludge experiments began during late winter. After developing ideas for general operation of a converted Imhoff tank along the continuous-flow activated-sludge method the first question to decide was the selection of suitable porous material, through which air in small bubbles was to be admitted to the mixture of sewage and sludge. Experiments were conducted in an iron cylinder to determine the necessary pressure and the volume of air passed through various types of porous material. Carborundum, alundum, sand and cement, filtros, and unglazed tile were the materials tested, specimen samples having been furnished by the various manufacturers. The apparatus consisted of an iron cylinder, flanged at each end, with plate glass to allow easy inspection. Inside the cylinder a disc of the material, 3 in. $\times$ 1 in., was clamped to a recessed flange, which in turn was attached to a compressed-air container. Mercury tubes and valves were arranged to measure the pressure and to regulate the volume of air. Water was put into the iron cylinder to cover the disc in order that some idea could be obtained regarding the size of air bubbles. When air was admitted to the flange it escaped by passing through the porous disc in small bubbles. Pressures, both pre-disc and post-disc, were maintained, equaling those in the bottom of the converted Imhoff tank. A record was kept of the pressures necessary and the volumes of air passing through the disc, and curves were drawn.

The cement and unglazed tile discs broke on being clamped to the flange and were eliminated because of their unreliable strength. The filtros tile needed but a few inches of head to force air through it but was discarded because the bubbles emitted were too large. Both carborundum and alundum were acceptable because of the smallness of the bubbles, but carborundum discs are less expensive. It was necessary to exert greater pressure on carborundum than on filtros, but the great advantage of having very small bubbles, thereby giving a larger contact per unit volume, is more important.

Five 4-liter bottles nearly filled with various mixtures of sewage and sludge were aerated from March 3 to about June 10. The information sought was to determine the mixture that produced most quickly an activated sludge, the rate at which the sewage could be purified, and the composition and other features of the sludge itself.

The tests made May 17, 1915, give an idea of the purification obtained under this laboratory method of aeration: the results are expressed in parts per million.

No.	CONTENTS OF BOTTLES		AMMONIA NITROGEN	NITRATE NITROGEN	DISSOLVED OXYGEN CONSUMED
	Per cent sludge	Balance			
1	20 (settling basin)	Raw sewage	0.9	6.2	0.6
2	None	Raw sewage	0.2	3.0	..
3	20 (settling basin)	Filter effluent	0.8	2.6	0.8
4	20 (settling basin)	Very fresh sewage	0.5	9.8	0.5
5	20 (hydro tank)	Raw sewage	0.3	7.2	2.0

The supernatant liquid was drawn from Bottles 1, 3 and 4 four times a day, and from 2 and 5 twice a week. Samples 1, 3 and 4 produced activated sludge within 3 wks., but the fresh sludge from the hydro tank needed about 6 wks. to become activated. This tended to prove that the sludge or humus from the sprinkling filters has characteristics somewhat similar to activated sludge.

Bottle 3 was covered, May 14, with a cloth to exclude light absolutely in order to render conditions similar to those at the bottom of a large tank. Subsequent analysis showed that the absence of light had no noticeable effect on the activated-sludge organisms.

A sample of sludge taken from Bottle 1, May 13, had a total nitrogen content on a dry basis of 4.39 per cent, which is a higher figure than any determined on our ordinary sludge and more than twice as high as the average nitrogen content of ordinary digestion-tank sludge. The low average figures for nitrate nitrogen in the effluent apparently show that most of the nitrogen in all forms stays in the sludge. This, of course, makes it more valuable as a fertilizer. The first English experiments last year showed that sludge produced by this method contained about three times as much nitrogen as did ordinary sludge.

During the spring, work was done in arranging Imhoff Tank 3 for operation on a continuous-flow activated-sludge basis. A series of pipes leading to 79 discs of No. 120 grit carborundum 6 in. $\times$ 1 in. were laid on the hopper bottom of the tank and connection was made by a 2-in. down pipe to a Hollingsworth blower, belt-driven by a motor. The tops of all the discs were brought as near as possible into the same horizontal plane. Sludge from the settling basins was dumped into the tank and air was pumped continuously into the mixture of sludge and raw sewage after August 5. A 12-in. iron pipe set upright and filled with graded gravel, over which clean water was sprayed, was placed in the air line between the blower and the porous discs. The air passed upward through the gravel, and the apparatus was designed to clean the air of any particles of dust or oil vapor from the blower.

Aeration was continued with the original loading of sludge and sewage till August 17, when raw sewage was allowed to flow for two days continuously through the tank. About 0.25 second-foot of sewage probably passed through. In this short time the effluent went back to its raw state showing that the sludge had lost its ability to purify. The flow of sewage was stopped and more sludge was at once dumped into the tank till a sludge ratio of about 30 per cent was attained. No more raw sewage was allowed to enter the tank till September 20, when a small stream was continuously passed through with a stream of purified sewage. The air has been roughly measured at about 5 volumes per volume of raw sewage. The operation has remained the same to date.

It was found necessary to agitate the sludge which settled underneath the grid of porous discs. This was done by putting a 1-in. pipe down the sludge pipe and attaching it to the flushingwater system. The purified sewage, from this system traveling at high velocity, tends to stir up the settled sludge, which otherwise would become septic and create conditions unfavorable to the life and increase of activated-sludge organisms. It is hoped that this agitation may be discontinued when the inflowing raw sewage has been increased to such volume that it is itself capable of performing the necessary agitation. Whether this purified sewage has a good or a bad effect on the effluent is uncertain. The effluent from the tank is now clear and sparkling. A sample taken October 4 has the following constituents:

Sludge ratio.....	27 per cent
Nitrate nitrogen.....	Trace
Ammonia nitrogen.....	12 parts per million
Dissolved oxygen consumed.....	2.6 parts per million
Dissolved oxygen.....	1.1 parts per million

The low figure of dissolved oxygen consumed indicates that no nuisance would occur by running an effluent of this character into a small stream. At the present slow rate of flow the raw sewage has an oxidation and sedimentation period of about 24 hrs., equivalent to a total tank replacement once a day. It is intended to increase gradually the rate of flow till a maximum is obtained.