THE ACTIVATED-SLUDGE METHOD OF SEWAGE TREATMENT

BY

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By F. W. Mohlman.

INTRODUCTION

The Nuisance Removal Act, passed by the British Parliament in 1855, at the close of a severe cholera epidemic, marks the beginning of the scientific study of the chemistry and biology of sewage. This was the first appreciation of the necessity for treating sewage in such a manner as to render it nonputrescible.

Since 1855 innumerable theories have been advanced, and many processes have been tried but the ideal process has not yet been found. Plants which were among the first constructed, and plants representing all processes having any merit at all are still in use.

Disposal by dilution in streams was the earliest method and is still in most general use in the United States. In 1915,[19] 83 per cent of the 41,800,000 people in the United States who were connected with sewerage systems discharged raw sewage into watercourses, lakes, or the ocean.

Broad irrigation is one of the older methods, and is still in use at the sewage farms of Paris and Berlin. The immense amount of land required has prevented extensive adoption of this practice.

Chemical precipitation has been used extensively. The sewage is treated with lime, lime and iron, alum, or a combination of these chemicals and the precipitate formed is allowed to settle. Although this process is still in use, it is limited because of the large amounts of comparatively worthless sludge produced, and because of the necessity of further treatment in order to obtain complete purification of the sewage.

When septic tanks were invented it was thought that the most satisfactory solution of the sewage-disposal problem had been found. The septic tank is still in general use in the United States but the early claims that all organic matter would be destroyed have not been substantiated. Some of the solid organic matter applied in the sewage is liquified and gasified but at times sludge is discharged with the effluent. The tanks require occasional cleaning, the sludge has little value as a fertilizer, and the odor from such tanks is

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usually very bad. Purification by this process is not complete, and if it is used in conjunction with further treatment, and septic action is carried too far, complete purification of the sewage is retarded.

Until recently the septic tank has been considered the most satisfactory preliminary treatment, but it has been gradually supplanted in new installations by the Imhoff tank. The special advantage which the Imhoff tank has over the septic tank is its two-story construction by which the settling solids and the gases of fermentation are separated from the incoming sewage. This tank is open to the same objection, however, as the septic tank for it also produces a large amount of valueless sludge.

Some means of oxidation is necessary for the final treatment of sewage. The intermittent sand filter was the first type to be used successfully in America, and under certain conditions is still a very satisfactory method of treatment. The great objection to the sand filter is the excessive amount of land required and the expense of construction when sand of the proper quality is not procurable. These objections practically eliminate the sand filter from installations for large cities. Although the capacity can be increased by preliminary treatment of the sewage, there is also an increased production of worthless sludge.

The contact filter has fallen into disuse because of the variable degree of purification effected, and because frequent cleaning and careful attention are required. Preliminary treatment is necessary with contact filters.

The sprinkling filter is widely used at the present day, and yet it has several disadvantages. Its construction requires a great deal of land and immense quantities of crushed stone. The effluent is of variable quality and contains considerable suspended matter, which must be removed in secondary settling basins. Odors are sometimes very pronounced and a justifiable objection is the presence at certain seasons of myriads of flies, gnats and bugs. The production of sludge is unavoidable.

Imhoff tanks for preliminary treatment and sprinkling filters for final treatment are usually recommended for present-day installations. In all the methods mentioned the disposal of the sludge is a great problem. Because of the small amount of fertilizing elements it contains it is practically worthless, and often entails considerable expense for its disposal. The situation is comparable to that which exists in gold mining, where millions of dollars worth of gold are present in tailings from which the metal cannot be recovered profitably. Millions of dollars worth of nitrogen and phosphorus are present in sewage, only awaiting some process by which they may be recovered profitably. With the propaganda of conservation of our resources being pushed so actively at the present time, this by-product of our modern civilization should not be overlooked. Any process that will recover these elements profitably must surely be ranked as one of the greatest discoveries of the century. The process of treating sewage by aeration in the presence of activated sludge promises in certain cases to recover this nitrogen and phosphorus profitably and to compete, from the standpoint of purification, with any of the present methods.

HISTORICAL REVIEW

The earliest attempts to oxidize sewage by aeration were made by Dupre and Dibdin[9] on the sewage of London and by Dr. Drown[7] on the sewage of Lawrence, Massachusetts. They found that oxidation accomplished in this way was a very slow process, and accordingly not at all practicable.

In 1892 Mason[18] and Hine conducted experiments on the oxidation of sewage by means of aeration. They concluded that air had but little oxidizing effect on sewage.

In 1894 Waring[20] attempted to apply air on a working scale at Newport, R. I., but his project was unsuccessful.

In 1897 Fowler[10] aerated the effluent from the chemical precipitation tanks at Manchester, England, but without accomplishing any considerable degree of purification. In 1911 aeration was again attempted. Black and Phelps[6] studied the possibility of aerating the sewage of New York City. They aerated sewage in tanks filled with inclined wooden gratings for varying periods up to twenty-four hours. The oxidation was so slight that determinations of nitrogen showed practically no purification, although some measure of improvement was indicated by the incubation tests. Black and Phelps recommended the process for a large-scale installation but it was not adopted.

Clark, Gage, and Adams[7,8] had tried aeration of sewage at the Lawrence Experiment Station, but had been unable to obtain satisfactory results until 1912. In that year, however, they were able to nitrify sewage successfully by aeration for twenty-four hours in a tank containing vertical slabs of slate placed about one inch apart, and covered with a zoogleal mass of colloidal matter deposited from the sewage. They submitted the effluent to further treatment for they did not claim that the aeration would entirely obviate filtration.

Gilbert J. Fowler[10] of Manchester, England, had tried aeration with some modifications on English sewages, but had obtained only indifferent results. Upon his return to England after a visit to Lawrence in 1912, he suggested work on aeration to Edward Ardern and W. T. Lockett, resident chemist and assistant chemist, respectively, at the Davyhulme Sewage Works of Manchester. On April 3, 1914, they reported[2] the remarkable results which they had obtained in their preliminary investigations.

In their first experiment, Ardern and Lockett aerated samples of Manchester sewage in gallon bottles, until complete nitrification was accomplished; the aeration was affected by drawing air through the sewage with an ordinary filter pump.

Aeration for about five weeks was required to obtain complete nitrification. The clear oxidized liquid was then removed by decantation, raw sewage added to the deposited sludge, and aeration continued until the sewage was again completely nitrified. This procedure was repeated a number of times. The amount of deposited solids increased, and the time required for complete nitrification decreased until eventually raw sewage was completely nitrified in six to nine hours.

The sludge, which induced such active nitrification was called "activated sludge" by Ardern and Lockett.

In August, 1914, Edward Bartow[5] saw the work in progress at Manchester, and upon his return to this country, suggested that experiments with activated sludge be started at the University of Illinois.

EXPERIMENTAL WORK

EXPERIMENTS IN BOTTLES

In the first series of experiments, sewage, collected as needed from the main outfall sewer of Champaign, was aerated in three-gallon bottles. The sewage was strong and fresh and contained no industrial wastes.

Aeration of sewage without sludge. A gallon of sewage, collected at 9 a. m. on November 2, 1914, was aerated until completely nitrified. An unmeasured amount of compressed air from the University supply was blown into the sewage through glass tubes. This process repeated with different samples of sewage when no activated sludge was present showed the course of the purification (see Table 1 and Figure 1). The ammonia nitrogen decreased, at first gradually, then more rapidly as the aeration continued. The nitrite nitrogen increased in proportion to the decrease of ammonia nitrogen. After the nitrite nitrogen

TABLE 1.—AERATION OF SEWAGE IN 3-GALLON GLASS BOTTLES WITH NO ACTIVATED SLUDGE PRESENT. AIR DISTRIBUTION THROUGH GLASS TUBE.

Date.	Time [*Days.*]	Nitrogen. [*Parts per million.*]			
		Ammonia.	Albuminoid.	Nitrite.	Nitrate.
Dec. 18	0	38.00	5.20	.07	.37
Dec. 19	1	30.00	4.20	.02	.38
Dec. 21	3	28.80	4.00	.11	.45
Dec. 28	10	22.00	3.60	5.00	.20
Dec. 29	11	8.00	2.60	16.00	.40
Dec. 30	12	1.60	2.40	23.00	1.00
Dec. 31	13	.36	1.88	28.00	2.00
Jan. 1	14	.16	1.48	31.00	1.00
Jan. 2	15	.....	.....	33.00	.....
Jan. 4	17	.....	.....	33.00	.....
Jan. 5	18	.....	.....	30.00	.....
Jan. 6	19	.28	1.92	27.00	5.00
Jan. 7	20	.44	1.84	14.00	18.00
Jan. 8	21	.28	1.68	.30	31. 0
Jan. 9	22	.24	1.60	.05	31.95

had reached a maximum and the ammonia nitrogen was practically all oxidized, there was a relatively sudden change of nitrite into nitrate nitrogen. The complete aeration of sewage in four different experiments gave concordant results.

Aeration of sewage with activated sludge. Activated sludge was built up in the manner suggested by Ardern and Lockett.[20] Sewage was aerated to complete nitrification, the supernatant liquid decanted

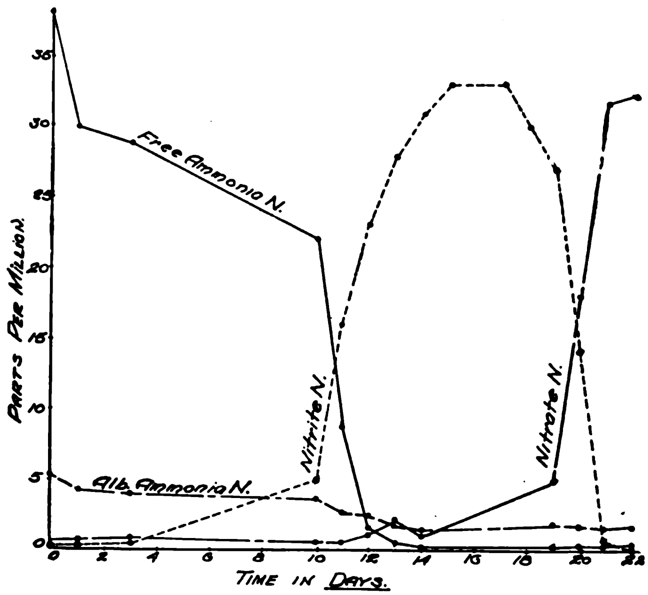

Figure 1.—Aeration of sewage in 3-gallon glass bottles with no activated sludge present. Air distribution through glass tube.

after the suspended matter had settled. This process was repeated and sludge accumulated. The time required for nitrification decreased very rapidly and on the seventh treatment nitrification was complete in 12½ hours. On the thirtieth treatment, with about 33 per cent of sludge, the time required for complete nitrification was between four and five hours.

The course of the reaction was very different from that when no activated sludge was present (see Table 2 and Figure 2). The ammonia nitrogen decreased rapidly, nitrate nitrogen increased as ammonia nitrogen decreased, and nitrite nitrogen never reached a high amount as in the previous experiment (see Table 3).

TABLE 2.—AERATION OF SEWAGE IN 3-GALLON GLASS BOTTLES IN PRESENCE OF ACTIVATED SLUDGE (1 SLUDGE: 3 SEWAGE). AIR DISTRIBUTION THROUGH GLASS TUBE.

Date.	Time. [*Hours.*]	Nitrogen. [*Parts per million.*] Ammonia.	Nitrite.	Nitrate.
Feb. 6	0	22.00	1.80	2.80
Feb. 6	2	9.00	6.00	10.40
Feb. 6	4	.18	4.00	16.80
Feb. 6	6	.20	.10	23.90
Feb. 6	8	.18	.10	23.90

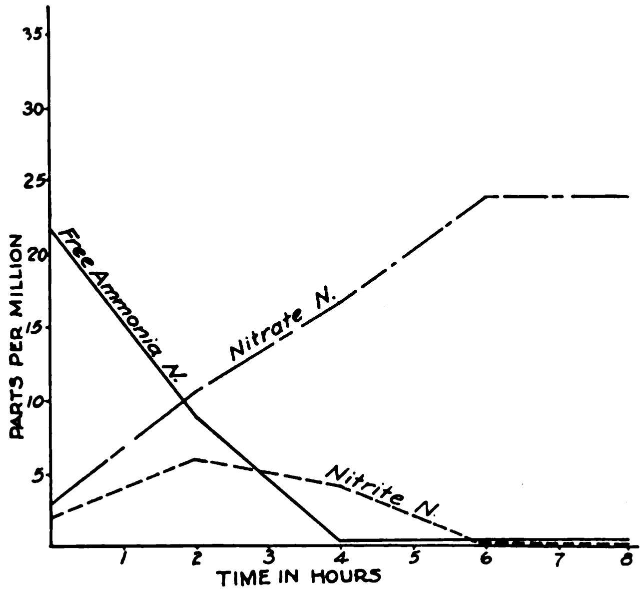

Figure 2.—Aeration of sewage in 3-gallon glass bottles in presence of activated sludge (1 sludge: 3 sewage). Air distribution through glass tube.

TABLE 3.—FORMATION OF NITRITE NITROGEN CAUSED BY AERATION OF SEWAGE IN PRESENCE OF ACTIVATED SLUDGE.

[Parts per million]

Date.	Series A.		Series B.	
	Aeration [*Hours.*]	Nitrite Nitrogen.	Aeration [*Hours.*]	Nitrite Nitrogen.
Jan. 9	0	.18		
	2	.01		
	4	.00		
	6	.20		
	8	.43		
	9	1.25		
	10	3.00		
	11	.40		
	13	.10		
Jan. 11	0	.00	0	.00
	1	.00	1	.00
	2	.00	2	.00
	3	.01	3	.10
	5	.02	5	4.00
	6	.02	6	4.50
	7	.10	7	6.50
	12	.05	12	.30
	24	.00	24	.15
Jan. 16	0	.30	0	.30
	1	.55	1	.00
	2	1.60	2	.30
	3	3.60	3	1.65
	5	6.60	5	3.60
	1 hour settling		1 hour settling	
	5	6.40	5	3.20
	6	6.00	6	3.40
	6	7.60	6	3.60
	7	8.40	7	3.60
	9	8.60	9	8.00
	24	.15	24	.20
Jan. 18	0	.00	0	.00
	1	.00	1	.00
	3	.10	3	.05
	4	.40	4	.15
	6	1.00	6	.25
	1 hour settling		1 hour settling	
	8	1.50	8	.25
	9	2.40	9	.20
	10	1.70	10	.15
	11	.70	11	.10
	20	.05	20	.05
Jan. 20	0	.00	0	.00
	9	3.80	9	8.00
	10	4.00	10	7.40
	11	4.50	11	7.60
	12	3.90	12	5.40
	13	.10	13	.20
	14	.10	14	.10

The reactions with and without activated sludge differ greatly as may be seen in Tables 1 and 2 and Figures 1 and 2. The nitrification in both experiments follows the nitrogen cycle, that is, nitrogenous organic matter is oxidized to ammonia nitrogen then to nitrite and finally to nitrate nitrogen. In aeration of sewage without sludge the last two stages are quite distinct, but in the presence of activated sludge, the formation of nitrite nitrogen is immediately followed by oxidation to nitrate nitrogen. In other words, the speed of the reaction

Nitrite + O = Nitrate

is nearly equal to that of

Ammonia + O = Nitrite

Since the oxidation is biological, this would seem to show the presence of great numbers of nitrite- and nitrate-forming bacteria in the activated sludge. These forms have been isolated from the sludge by Russel.[21]

These experiments led to the following theory of the action of activated sludge.

The oxidation of the organic matter of sewage is accomplished by biological agencies since both air and bacteria are essential. The bacteria must be of the proper type, that is, nitrifying forms. The reaction is:

Ammonia nitrogen + Nitrifying bacteria + Air = Nitrate nitrogen.

In the aeration of sewage without sludge, the nitrifying forms are very few in number, because conditions are usually unfavorable for their presence and growth in sewage as it flows through sewers. At times, during hot weather, the sewage is entirely anaerobic, which means practically the elimination of all nitrifiers. With the few nitrifying bacteria present, the complete nitrification of sewage without sludge must take place slowly.

With the accumulation of activated sludge, and by the maintenance of continuous aerobic conditions in the aerating tanks there are optimum conditions for the growth of nitrifying bacteria. These bacteria increase enormously, and the time necessary for complete nitrification is greatly shortened.

The above theory may account for the accelerated nitrification but other features of the process, such as the clarification and reduction in bacteria are probably caused by other agencies.

The clarifying efficiency of the activated-sludge process is remarkable. Most of the effluents contain very little colloidal matter. The removal of colloidal matter must undoubtedly be caused by the absorptive power of the spongy, flocculent sludge acting in conjunction with the "scrubbing" effect of the air. The sludge may also remove the bacteria in about the same manner as a chemically precipitated floc. Russel[21] has shown that an average of 95 per cent of the bacteria are removed in 4-hours' aeration in the presence of 25 per cent of sludge.

T. Chalkley Hatton,[15] who has conducted extensive experiments with activated sludge at Milwaukee, reports that 97 per cent of bacteria are removed in 3½ hours' aeration in the presence of 25 per cent of sludge.

To prove whether or not the action of enzymes assists in clarification and bacterial removal, 25 per cent of clarified effluent was added to raw sewage. No clarification resulted other than that caused by the dilution. It is not likely that enzymes are of much assistance in clarification.

EXPERIMENTS IN LABORATORY TANK

The experiments just described yielded accurate data concerning certain chemical and biological features of the process, but it was realized that the volume of sewage treated was small, the air distribution poor, and the volume of air undetermined. In order to treat larger volumes of sewage, to get a better distribution of air, and to measure the air, a new apparatus was built.

Description of apparatus. A tall wooden box, 9 inches square and 5 feet deep, was fitted with a plate-glass front and back to permit easy observance of the air distribution and the condition of the sewage and sludge (see Figure 3). A porous plate 1½ inches thick and 9 inches square, of a patented material called "Filtros" was cemented

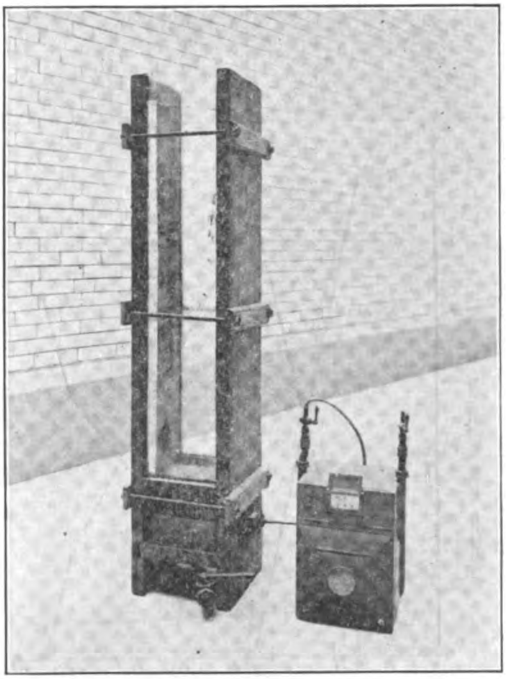

Figure 3.

four inches above the bottom of the tank. "Filtros" is manufactured by the General Filtration Co. of Rochester, New York. It is made of carefully graded quartz sand mixed with ground glass; when heated the glass fuses and binds the mixture firmly together. Air passes through the plate freely and in fine bubbles.

An inlet for air and an outlet for water which might filter through the plate, opened into the space below the plate. Compressed air from the University supply was measured through an ordinary gas meter. A siphon was used to remove the supernatant liquid after the sludge had settled. Experiments were carried on at room temperature.

Accumulation of sludge. The diffusion of the air through the plate reduced the time required for complete nitrification of the first sewage treated to 15 days (see Table 4 and Figure 4). The air re-

TABLE 4.—AERATION OF SEWAGE IN LABORATORY TANK WITH NO ACTIVATED SLUDGE PRESENT. UNIFORM DISTRIBUTION OF AIR THROUGH POROUS PLATE.

Date.	Time. [*Days.*]	Nitrogen. [*Parts per million.*] Ammonia	Albuminoid	Nitrite	Nitrate
Jan. 4	0	36.00	6.60	.01	.70
Jan. 7	3	34.00	3.40	1.20	.60
Jan. 11	7	0.40	3.00	32.00	2.00
Jan. 18	14	0.60	2.60	7.50	18.50
Jan. 19	15	0.80	2.20	.10	25.90

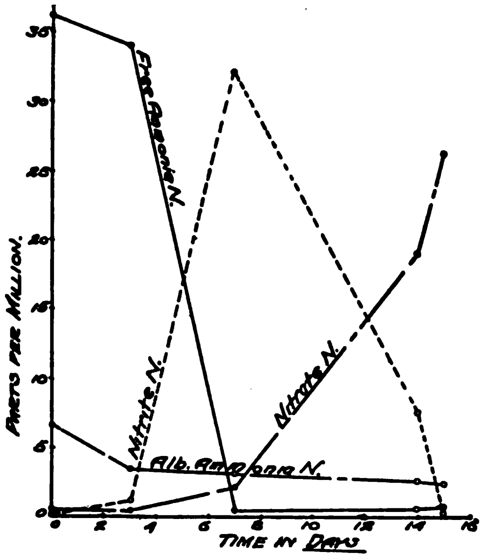

Figure 4.—Aeration of sewage in laboratory tank with no activated sludge present. Uniform distribution of air through porous plate.

quired for the 16 gallons of sewage in the tank amounted to 4,830 cubic feet. The raw sewage contained 36 parts per million of ammonia nitrogen and 0.7 part per million of nitrate nitrogen. The effluent contained 25.9 parts per million of nitrate nitrogen and 0.8 part per million of ammonia nitrogen.

In the second treatment, the time required for complete nitrification was but four days, with a reduction of the air to 1,270 cubic feet. The raw sewage contained 34 parts per million of ammonia nitrogen and practically no nitrate nitrogen. The effluent contained 23.8 parts per million of nitrate nitrogen and practically no ammonia nitrogen.

In the third treatment nitrification was complete in two days with the use of 720 cubic feet of air. The raw sewage contained 33 parts per million of ammonia nitrogen, the effluent contained 22.3 parts per million of nitrate nitrogen.

In the twelfth treatment, nitrification was complete in less than eight hours with the use of less than 128 cubic feet of air.

In the thirty-first treatment with sludge and sewage in the proportion of 1:5, nitrification was complete in less than five hours; 35 cubic feet of air were used, equal to 0.20 cubic foot per square foot of surface area per minute or about 3 cubic feet per gallon of sewage. The effluent after one hour's aeration did not decolorize methylene blue in twelve days. The raw sewage contained 27 parts per million of ammonia nitrogen. The effluent contained 22.1 parts per million of nitrate nitrogen (see Table 5 and Figure 5).

The results obtained in this short period of aeration were excellent, but it was learned from later operation that such results could not be obtained consistently unless aeration was continued until all of the ammonia nitrogen was removed. The quality of the effluent depends upon the condition of the sludge which in turn depends upon the extent to which previous aerations have been carried. By aerating until

TABLE 5.—AERATION OF SEWAGE IN LABORATORY TANK IN THE PRESENCE OF ACTIVATED SLUDGE (1 SLUDGE: 5 SEWAGE). UNIFORM DISTRIBUTION OF AIR THROUGH POROUS PLATE.

Date.	Time. [*Hours.*]	Nitrogen. [*Parts per million.*] Ammonia	Nitrite.	Nitrate.
Feb. 24	0	27.00	.05	.59
	1	13.00	2.40	6.00
	2	8.20	2.80	10.80
	3	3.70	3.40	15.00
	4	.20	2.60	10.60
	5	.20	0.30	22.10

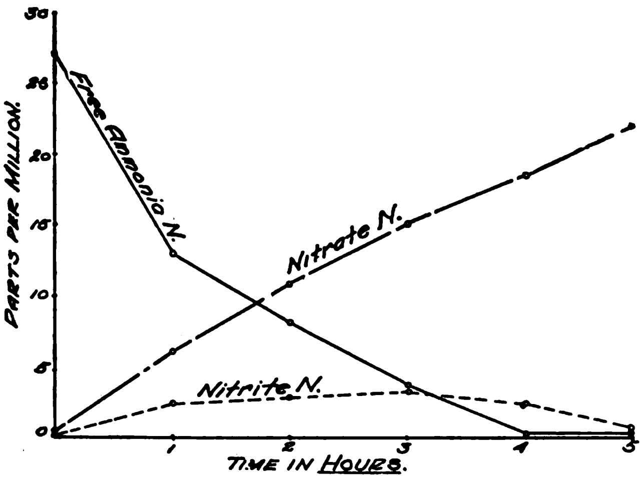

Figure 5.—Aeration of sewage in laboratory tank in the presence of activated sludge (1 sludge : 5 sewage). Uniform distribution of air through porous plate.

ammonia nitrogen has disappeared, the sludge becomes more effective for further use.

In accumulating sludge in the laboratory tank, the periods of aeration varied. The sewage was not changed at night and many sewages were aerated for a long time after the ammonia nitrogen had disappeared.

With this method of operation, very excellent results were obtained in a short period of aeration, but such results could not be maintained, unless the sewage were overtreated occasionally. If the ammonia nitrogen is not completely oxidized there is but slight formation of nitrite and nitrate nitrogen, the amounts becoming smaller in each succeeding effluent. When once the sludge becomes inactive it requires considerable aeration to re-activate it.

Owing to the impossibility of controlling the temperature of the room at night, high temperatures occasionally prevailed, which may have caused the sludge to lose its activity. When the sludge was in this inactive condition, it would not settle, but appeared very colloidal, and sometimes had a slightly septic odor. If it were aerated for a long time with occasional addition of fresh sewage, however, it would again become normal.

Quantity of sludge. When the sludge had increased to about 33 per cent of the total volume of the tank it was removed to a depth of 6 inches above the plate and dried. Eight portions of sludge were removed, the amount of water present was determined, and the weight of dry sludge per million gallons of sewage calculated. The results of these determinations are given in Table 6.

TABLE 6.—QUANTITY OF SLUDGE OBTAINED FROM AERATION OF SEWAGE IN LABORATORY TANK.

Date.	Grams wet	Grams dry	Per cent water.	Gallons of sewage.	Kgms. of dry sludge per million gal. sewage.
Mar. 15	4,400	75	98.3	...	....
Mar. 18	4,400	57	98.7	...	....
Mar. 23	9,400	132	98.6	...	....
Mar. 31	14,400	185	98.7	135	1,400
Apr. 8	9,750	121	98.8	196	620
Apr. 15	7,400	154	97.9	214	720
Apr. 30	8,300	185	97.8	360	515

Average per cent water in sludge 98.4.

There were wide variations in the amount of sludge formed per unit of sewage. When sludge was removed frequently, the amount formed appeared greater than when it was allowed to remain in the tank for a longer period. For example, in 3 days, from March 23 to March 26, 2550 kilograms per million gallons, in 5 days, from March 26 to March 31, 1,400 kilograms per million gallons, and in 8 days, from March 31 to April 8, only 620 kilograms of sludge per million gallons of sewage were formed.

Sludge was probably liquefied by overtreatment. This theory was verified by dividing a portion of sludge into two parts, drying one portion immediately, and aerating the other for 24 hours with 4 volumes of purified effluent before drying. The loss amounted to 1.1 grams, or approximately 5 per cent.

Weight of sample dried immediately................	23.7 grams
Weight of sample dried after 24 hours' aeration......	22.6 grams
Loss by over-aeration	1.1 grams

The large amount of sludge obtained may have been caused by the fact that the sewage used was collected at 9 a. m. when the Champaign city sewage at the point of collection was strongest and contained the maximum amount of suspended matter, probably 2 to 3 times the average. If the suspended matter were completely removed from a sewage containing 300 parts per million of suspended matter, 1,120 kilograms of dry sludge would be obtained per million gallons of sewage. Sewage containing 135 to 365 parts per million of suspended matter, assuming 100 per cent retention of suspended matter in the activated sludge, would give the amount of the dry sludge obtained.

Analyses of the sludge were made by W. D. Hatfield[4], as a part of a thesis on the fertilizer value of activated sludge. The sludge was found to contain from 3.5 to 6.4 per cent of nitrogen.

A phenomenon was noted in connection with the operation of the tank which was thought at the time to be of importance. Small red worms were present in the sludge in such numbers that in places the sludge had a red appearance. The species was identified by Professor Frank Smith, of the University of Illinois, as Aeolosoma hemprichii, an annelid worm about 2 to 5 millimeters long and rather slender. It is found in water containing an abundance of decaying organic matter, and thrives especially well where there is much fermentation, as in a water contaminated with sewage but provided with an abundant supply of oxygen. It belongs to a group of worms in which reproduction occurs very rapidly by asexual methods. It feeds almost continuously on any small organic particles that it can obtain, and presumably consumes at least its own weight of organic matter every day.

Because of the facts noted above, it was thought that this worm was an important agency in the purification of the sewage. However, it was proved by Robbins Russel[21] that the worms were not essential, and that their presence was merely accidental and of no consequence. They were not found at any time in the larger-scale experiments reported later, and have not been found at other places except at Washington, D .C., where they were found in activated sludge obtained during the course of laboratory experiments.

Their presence in the tank in the laboratory, and absence in the large tanks may have been caused by a number of factors; the laboratory experiments were conducted in a light room in a tank with glass sides, the temperature in the laboratory was higher, and the aeration was often continued until large amounts of nitrate nitrogen were formed. The worms disappeared at times when effluents were putrescible. Possibly nitrate is necessary for their growth and existence.

Effect on fish life. Considering that sustenance of fish life would be an excellent indication of the good quality of the effluent, some small fish obtained from the Salt Fork Creek near St. Joseph on April 17, 1915, were placed in a 20-liter jar which was filled with effluent from the tank. The liquid was aerated continuously and changed each time the effluent was removed from the tank.

The fish seemed to thrive at first, but in three days two of the smallest died. In seven days another died, and in ten days, shortly after the addition of a putrescible effluent, all of them died.

This test was inconclusive, as the degree of purification was variable during the period of observation. When the effluent was nonputrescible the fish seemed to suffer little discomfort, and had all of the effluents been stable, it is probable that the fish would have lived. It was proved, at least, that a nonputrescible effluent from the activated-sludge process, if aerated, is not immediately toxic to fish.

EXPERIMENTS IN CONCRETE TANK

The work with the laboratory tank was continued until April 30, 1915. On May 6, 1915, experiments on a larger scale were begun, using four concrete tanks built in the basement of the University power plant (see Figures 6 and 7). This location was chosen because it was the most convenient place that could be found for tapping the main sewer of the city of Champaign. The conditions under which the experiments were conducted were similar to those which would be obtained by housing a plant.

Description of tanks. Each tank is 3 feet 2 inches square, thus having an area of 10 square feet. Each tank is 8 feet 5 inches deep above Filtros plates 1½ inches thick, which are used for diffusing the air. These plates were considered to be the most satisfactory air-diffusing medium available.

In tanks A and B there are 9 plates, each 12 inches square, covering the entire floor.

In tank C there are three plates, covering three-tenths the area of the floor. They form a central trough to which the concrete sides slope at an angle of 45 degrees.

In tank D there is but one plate, covering one-tenth the area of the floor. The four concrete sides slope to the plate at an angle of 45 degrees.

The plates are set on steel T-bars 4 inches above the bottom of the tank. The space below is drained by a 2-inch pipe, and when a tank is being drained air pressure is released under the plates by a petcock attached to a one-inch pipe. If the pressure is not released, bubbles of air pass through the plates and stir up the sludge and supernatant liquid.

The air, obtained from the University compressed-air plant at a pressure of 80 pounds per square inch, is reduced by a pressure-reducing valve to 8 pounds per square inch. The quantity of air supplied is further regulated by a hand-operated valve before it passes through meters on each tank. These meters are the ordinary gas meters which were tested by the local gas company during the course

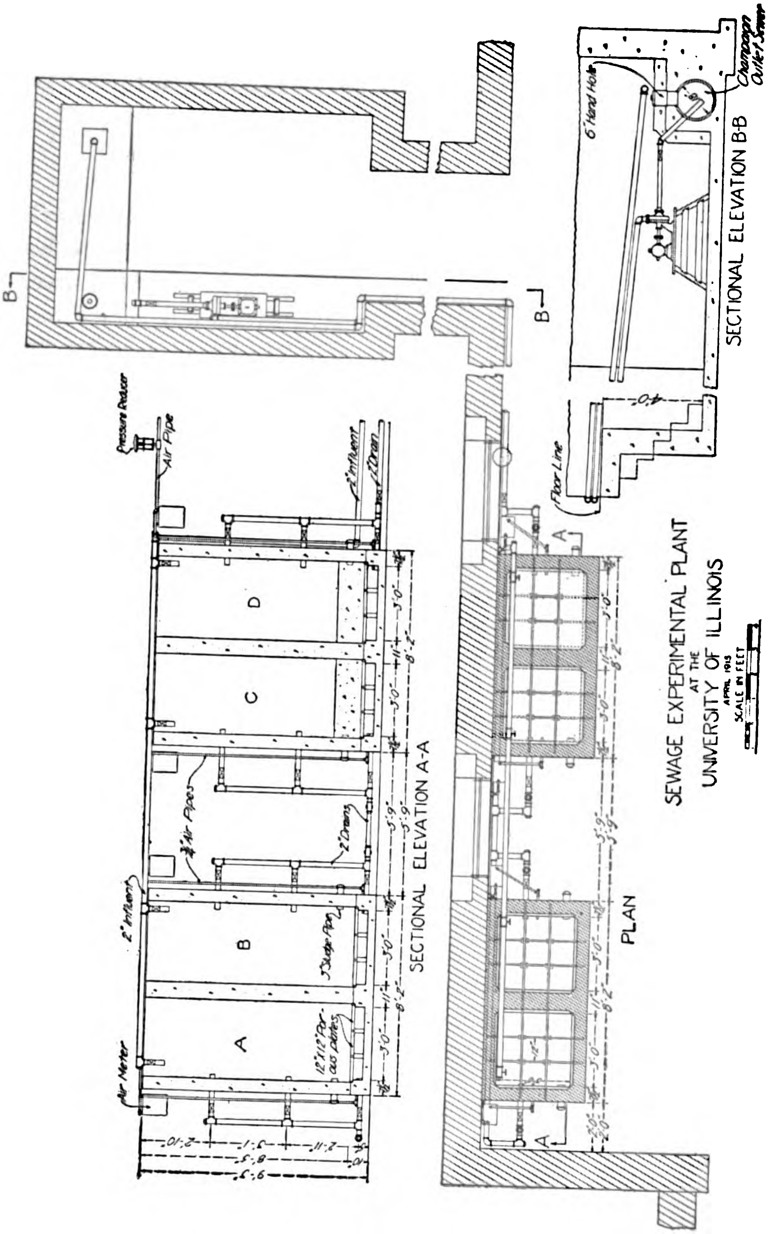

Figure 6.—Plan and elevation of concrete tanks.

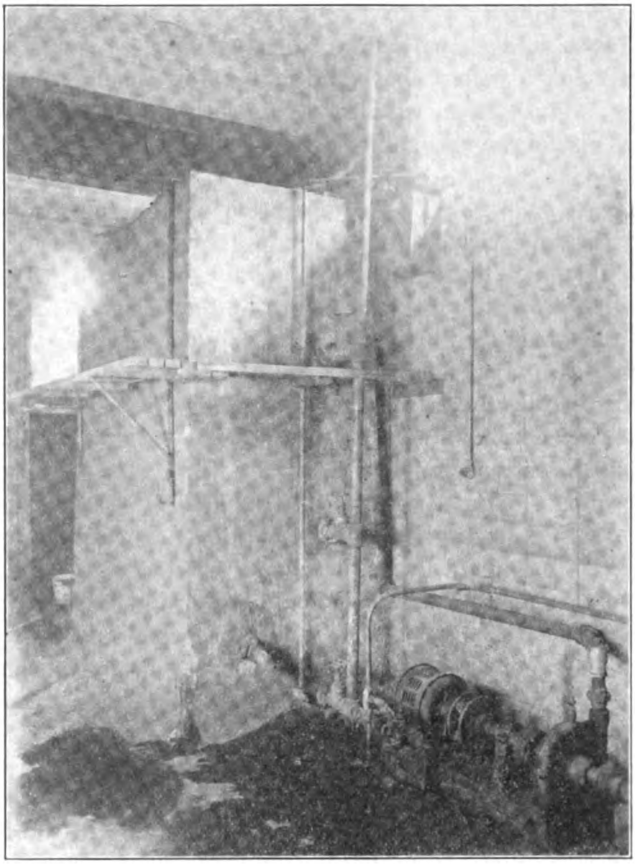

Figure 7.

of the experiments, and were found to register with a fair degree of accuracy. The pressure under which the air enters the tank is but little more than that necessary to balance the hydrostatic pressure of the sewage and the friction of the plates. It is equivalent to 8 inches of mercury, or a little less than 4 pounds per square inch. The friction in passing through the plates amounts to but a fraction of a pound pressure.

Two outlets for the effluent are, respectively, 2 feet 6 inches, and 5 feet 7 inches above the plates. Changes were made in these outlets for the later experiments.

Raw sewage was pumped as needed by a 2-inch centrifugal pump direct-connected to a 2-horsepower 3-phase motor. This pump will fill one tank in 6 minutes. Each tank can be drained to the lower outlet in 8 minutes.

A 3-inch sludge pipe with a quick-opening valve was introduced into each tank 5 inches above the plates, for removing sludge when necessary. This design was faulty as the pipe should have entered the tank just above the plates in order that all of the sludge might be removed.

Plan of operation. The operation of the four tanks was so planned that special features might be studied by varying (1) the strength of sewage treated, (2) the amount of air used, (3) the quantity of sludge present, (4) the length of the period of aeration, and (5) the amount of air-diffusing area. The quantity of sewage treated per filling was approximately constant, the amount varying only slightly according to the amount of sludge present. Approximately 400 gallons were added at each filling.

Accumulation of sludge. The time required for the accumulation of the requisite quantity of activated sludge is of great importance from a practical standpoint. In the original experiments of Ardern and Lockett[2] and in our first experiments the sewage was aerated until all ammonia nitrogen had been oxidized. Under these conditions nearly two months are required for the accumulation of sufficient activated sludge to operate a plant. In the meantime but a very small portion of the sewage can be treated. In order to shorten this long period of preparation, sludge was accumulated by removing the effluent before the ammonia nitrogen was entirely oxidized to nitrate nitrogen. In this way some degree of purification was obtained as soon as operation began and sludge was accumulated more rapidly. The rapid method of accumulating sludge was studied by comparative operation of two tanks. Tanks A and B were put in operation on

TABLE 7.—ACCUMULATION OF SLUDGE DURING AERATION OF SEWAGE IN TANK A. AERATION CONTINUED FOR 11 DAYS.

Date.	Period of Aeration [*Hours.*]	Amount of Air. [*Cu. ft.*]	Nitrogen. [*Parts per million.*] Ammonia.	Nitrite.	Nitrate.	Total Organic.	Oxygen-Consuming Capacity.	Stability [*Per cent.*]
May 5	0	0	28.0	....	...	21.6	88.0	...
6	18.5	3,600	16.0	.35	.95	10.4	21.2	...
7	42.5	.....	15.0	.35	.....	5.3	22.0	...
8	72.	9,430	12.0	.45	.75	5.0	22.8	...
9	98.	12,480	18.0	.45	.85	4.2	20.8	...
10	121.	15,400	17.0	.50	1.00	4.0	20.4	90
11	144.	18,220	14.0	1.5	.10	3.6	20.4	96
12	167.	21,440	14.0	2.0	.10	4.2	22.8	100
13	192.	25,340	15.0	3.3	.10	5.2	24.0	100
14	218.	29,100	13.0	4.7	.20	4.8	25.2	100
15	238.	32,080	10.0	12.5	.50	5.6	32.8	100
16	270.	35,930	0.4	26.0	1.0	6.2	35.0	100

May 5, 1915. The sewage in tank A was aerated without interruption for eleven days until all ammonia nitrogen was oxidized (see Table 7), that in tank B was changed every 24 hours during the same period (see Table 8).

TABLE 8.—ACCUMULATION OF SLUDGE DURING AERATION OF SEWAGE IN TANK B. SEWAGE CHANGED EVERY 24 HOURS DURING 11 DAYS' AERATION.

Date	Sewage	Amount of Air. [Cu. ft.]	Period of Aeration. [Hours.]	Nitrogen. [Parts per million.] Ammonia.	Nitrite.	Nitrate.	Total Organic.	Oxygen Consuming Capacity.	Stability [Per cent.]
May 5	Raw	2830	24	28.0	....	....	21.6	88.0	...
5	Eff.	....	..	16.0	.35	.95	10.4	21.6	...
6	Raw	2430	23	19.0	....	....	19.3	60.0	...
6	Eff.	....	..	15.0	.45	.95	9.9	22.4	37
7	Raw	3840	23	24.0	....	....	12.0	42.0	...
7	Eff.	....	..	15.0	.50	1.4	6.2	22.4	75
8	Raw	2660	25	16.0	....	....	9.6	29.0	...
8	Eff.	....	..	11.0	.4	1.8	5.4	12.0	84
9	Raw	2200	22	21.0	....	....	15.2	47.0	...
9	Eff.	....	..	16.0	.5	2.3	5.3	14.4	84
10	Raw	1650	21	20.0	....	....	11.5	46.0	...
10	Eff.	....	..	12.0	1.0	1.0	4.2	15.2	90
11	Raw	3990	22	18.0	....	....	15.0	75.0	...
11	Eff.	....	..	8.0	1.7	1.0	5.0	21.2	90
12	Raw	1750	24	19.0	....	....	16.7	83.0	...
12	Eff.	....	..	10.0	1.6	.5	4.6	19.2	96
13	Raw	2450	24	18.0	....	....	12.2	52.0	...
13	Eff.	....	..	11.0	3.6	.4	5.4	23.6	97
14	Raw	1530	19	27.0	....	....	15.4	64.0	...
14	Eff.	....	..	18.0	5.0	.5	5.0	25.2	100
15	Raw	3900	31	23.0	....	....	12.5	70.0	...
15	Eff.	....	..	5.0	15.0	1.0	6.5	50.0	100
16	Raw	1420	16	26.0	....	....	32.6	171.0	...
16	Eff.	....	..	4.0	20.0	2.0	5.4	48.00	100

Thus, during the 11 days, 12 times as much sewage was treated in B as in A. After one hour's settling in Imhoff cones, there was one per cent of sludge by volume in A, and 10 per cent in B. On May 16, after 11 days' aeration, the effluent from tank B was clearer than that from tank A.

After 11 days' continuous aeration of the sewage in tank A, using 35,930 cubic feet of air, ammonia nitrogen had been reduced from 28 to 0.4 parts per million, nitrite nitrogen increased to 26 parts per million, nitrate nitrogen to 1.0 part per million. Oxygen consumed was reduced from 88 to 35 parts per million, total organic nitrogen from 21.6 to 6.2 parts per million, and the supernatant liquid had a stability of 100 per cent.

After 11 days' aeration of the sewage and sludge in tank B, using 1,420 cubic feet of air, ammonia nitrogen was reduced from 26.0 to 4.0 parts per million, nitrite nitrogen increased to 20 parts per million, and nitrate nitrogen to 2.0 parts per million. Oxygen consumed was reduced from 171 to 48 parts per million, total organic nitrogen from

32.6 to 5.4 parts per million, and the effluent had a stability of 100 per cent.

The results obtained by changing the sewage in tank B every day were so much better than those obtained by continuous aeration of the sewage in tank A that this experiment in tank A was discontinued.

The operation of tank B was continued changing the sewage every 24 hours, until after 15 days, ammonia nitrogen in the effluent was less than 1.0 part per million. Then the sewage was changed every 12 hours and after 8 days ammonia nitrogen in the effluent was less than 1.0 part per million. Then the sewage was changed every 6 hours and after 4 days ammonia nitrogen in the effluent was again less than 1.0 part per million. The sewage was well nitrified by this sludge, and the sludge had the same appearance and properties as that accumulated by complete nitrification of each quantity of sewage added.

This comparison indicated that it was not necessary to aerate until all ammonia nitrogen was removed from the sewage, in order to obtain a satisfactory sludge.

After this activated sludge was accumulated in tank A by changing the sewage after 12 hours' aeration. The data correspond to those obtained during the operation of tank B on the 24-hour schedule. Stable effluents were obtained in 7 days; complete removal of ammonia nitrogen was accomplished in 18 days, after which the sewage was changed after 6 hours' aeration. The effluents obtained from tank A during this 6-hour cycle were in general as good as those obtained from tank B, in which sludge had been accumulated by changing the sewage once a day.

In a later experiment in tank C, sludge was accumulated by changing the sewage after 6 hours' aeration. Stable effluents were obtained in 15 days; removal of ammonia nitrogen to less than one part per million occurred in 20 days. The sludge accumulated in this way had the same characteristics as sludge accumulated by changing the sewage only when all the ammonia nitrogen was removed, and was apparently just as highly "activated."

The conclusion was reached that activated sludge can be accumulated by aerating each addition of sewage for six hours. It has been thought that the accumulation of sludge would be long, tedious process, and in order to shorten this process slurry from sprinkling filters,[2] Imhoff sludge,[22] and other kinds of sludge have been proposed as "starters." Our work showed that sufficient sludge could be obtained from Champaign sewage in a week, by aerating each addition of sewage for 6 hours, that no starter need be used, and that a considerable degree of purification could be obtained from the beginning of operation.

Operation of tanks A and B. Tanks A and B were operated continuously from May 21 until November 1. During this time 400 gallons of sewage were applied at each filling. Effluents were removed and sewage added 4 times a day, except in a few instances when the influent pipe was plugged up by rags or the motor refused to work. Such accidents account for most of the periods of overaeration. The amount of air applied and the time of aeration were variable. The amount of sludge remained approximately constant after 25 per cent had been obtained. Only once was sludge removed from either tank. On June 30 the sludge in tank A was well stirred, and 6 inches were removed and dried on a sand bed; the sludge was further dried on a steam bath, to a final weight of 485 grams. On July 9, 6 inches were removed from tank B; the dried sludge weighed 1,660 grams.

It was somewhat surprising to find that even though sludge was not removed, only 30 per cent had accumulated in tanks A and B. The failure to accumulate sludge may have been because it was drawn off with the effluent, or because it was digested and liquified in the tank as fast as formed. Sludge is liquified by overaeration, (see page 17) such as prevailed at times during this experiment with tanks A and B. Warm weather may have accelerated the digestion. Owing to the failure to accumulate sludge no data concerning the amount of sludge formed were obtained. Special determinations concerning this were made later with tank C (see page 30–33).

Analyses of the raw sewage and effluents from tank A from May 21 to November 1, were averaged by weeks (see Table 9). Similar data were obtained from the experiments in tank B but they are omitted since they are practically identical with those for tank A.

During the first period, from May 21-24, with very little sludge, effluents were not stable even with 12 hours' aeration and 2.0 cubic feet of air per gallon of sewage.

From May 25-31, effluents were approximately 90 per cent stable with 11 hours' aeration using 1.5 cubic feet of air per gallon of sewage. From June 1-7 effluents were of about the same quality with 11 hours' aeration using 1.5 cubic feet of air per gallon of sewage.

During the period of June 8-14, the time of aeration was reduced to 5 hours, and the air to less than one cubic foot per gallon. The effluents from the weak 3 a. m. sewage were stable, but those from the 9 a. m., 3 p. m., and 9 p. m. sewages were unsatisfactory. We have considered that a stability under 70 per cent indicates a poor effluent.

From June 15-21, with about 0.8 cubic foot of air per gallon, all effluents from 3 a. m. sewages were stable; those from 9 a. m. sewages were good, but the effluents from the 3 p. m. and 9 p. m. sewages were quite poor.

From June 22-28, the results were the same as those for the previous week.

During the period, June 29 to July 5, with one cubic foot of air per gallon all effluents from the 3 a. m. sewages were stable, but even with 1.5 cubic feet the other effluents were very poor.

From July 6-12 more air was applied, the average being 2.5 cubic feet per gallon, and longer aeration was given, resulting in stable effluents from all sewages.

During the next week, from July 13-19, the air was again reduced to about 1.0 cubic foot per gallon, the period of aeration to 5 hours; effluents were unsatisfactory.

From July 20-26, with 1.0 cubic foot of air per gallon and 4.5 hours' aeration, all effluents except those from 3 a. m. sewage were poor.

From July 27 to August 2, with 0.9 cubic foot of air per gallon, and 4.5 hours' aeration, all effluents were stable, but the raw sewage was very weak because of excessive rainfall.

During the entire month of August nitrification was good and all effluents were excellent. During the first and last weeks, however, because of the excessive rainfall, the raw sewage was very weak.

Normal sewage was obtained from August 10-23 and during this period 1.3 cubic feet of air per gallon and 4.6 hours' aeration gave very stable effluents.

During the first week of September, with 6 hours' aeration and 1.3 cubic feet of air per gallon stable effluents were still being obtained from normal sewage.

From September 7-13, with 5 hours' aeration and 1.1 cubic feet of air per gallon all effluents, except that from the 3 a. m. sewage, were very unsatisfactory.

During the period September 14-20, with 5 hours' aeration and 1.0 cubic foot of air, effluents were fairly stable. The raw sewage, however, was weak during this period.

From September 21 to October 4, even with 1.9 cubic feet of air per gallon and 6.7 hours' aeration, all effluents were very poor.

In order to determine whether the quality of the effluents could be improved by aerating the sludge alone for a certain period, no sewage

TABLE 9.—RECORD OF THE OPERATION OF TANK A, MAY 21-NOVEMBER 1, 1915.

Date.	Time of Filling.	Period of Aeration.	Amount of Air.	Raw.	Effluent.			
				Nitrogen. [*Parts per million.*]				Stability
		[*Hours.*]	[*Cu. ft.*]	Ammonia.	Ammonia.	Nitrite.	Nitrate.	[*Per cent.*]
May 21–24	9–11 a. m.	12.7	800	37.8	26.5	.15	.5	24
25–31	9–11 a. m.	10.7	740	21.4	12.4	3.6	3.3	83
	10–11 p. m.	11.6	590	17.4	9.6	4.9	3.5	91
June 1–7	10–11 a. m.	11.0	600	22.7	5.6	2.8	4.5	91
	11 p. m.	11.0	510	18.7	6.2	2.1	5.8	80
8–14	3 a. m.	5.0	320	10.2	3.8	1.7	6.9	99
	9 a. m.	5.8	390	31.7	14.3	1.3	2.1	70
	3 p. m.	5.0	310	17.8	14.3	.1	.6	54
	9 p. m.	5.0	300	21.7	12.4	.6	.9	74
15–21	3 a. m.	5.0	270	11.8	6.6	1.9	4.2	100
	9 a. m.	5.0	320	28.3	16.7	.7	1.3	81
	3 p. m.	5.0	290	17.1	14.3	.5	.4	48
	9 p. m.	5.0	270	19.3	14.0	.6	.5	52
22–28	3 a. m.	5.1	310	12.9	7.0	3.1	3.2	100
	9 a. m.	5.1	390	29.7	17.7	.9	.8	67
	3 p. m.	4.7	300	17.3	13.2	.2	.3	53
	9 p. m.	5.0	330	20.7	12.5	.9	.4	70
June 29–July 5	3 a. m.	5.0	400	16.7	10.8	.5	1.8	100
	9 a. m.	4.9	520	32.3	22.2	.1	.0	17
	3 p. m.	6.6	930	24.5	16.2	.6	.2	68
	9 p. m.	5.0	380	22.0	16.3	.0	.4	45
July 6–12	3 a. m.	4.5	1170	4.7	.3	1.1	11.1	100
	9 a. m.	14.5	1700	24.3	12.3	4.7	4.6	78
	3 p. m.	4.0	530	15.1	6.9	3.6	3.8	74
	9 p. m.	6.1	540	12.6	6.2	3.3	4.0	82
13–19	3 a. m.	4.5	370	8.2	2.0	1.8	2.6	99
	9 a. m.	4.5	530	23.7	10.3	1.3	2.0	61
	3 p. m.	4.5	420	13.3	8.1	.1	.5	62
	9 p. m.	6.2	400	17.3	9.9	.7	1.0	77
20–26	3 a. m.	4.5	420	10.5	5.2	1.6	47.7	98
	9 a. m.	4.5	510	31.1	17.8	.8	1.1	68
	3 p. m.	4.5	440	17.4	13.9	.3	.6	56
	9 p. m.	4.5	350	18.8	11.3	.4	1.0	..
July 27–Aug. 2	3 a. m.	5.4	420	5.0	2.1	2.5	9.5	100
	9 a. m.	4.5	350	14.7	9.3	1.3	10.8	85
	3 p. m.	4.5	350	7.9	6.1	.7	6.7	80
	9 p. m.	4.5	350	8.7	4.3	1.5	8.7	75
Aug. 3–9	3 a. m.	4.5	320	4.3	.2	16.2		100
	9 a. m.	5.4	410	17.4	7.2	12.3		93
	3 p. m.	4.5	340	9.2	6.1	7.7		90
	9 p. m.	4.5	360	10.4	2.4	9.6		100
10–16	3 a. m.	4.5	350	5.9	.7	8.6		95
	9 a. m.	5.4	610	30.1	8.2	6.2		..
	3 p. m.	4.5	580	16.3	1.5	5.7		..
	9 p. m.	4.5	420	16.1	2.9	4.1		..
17–23	3 a. m.	4.5	490	6.8	.0	9.7		..
	9 a. m.	4.5	520	28.8	10.7	5.1		..
	3 p. m.	4.5	570	12.8	4.4	5.8		..
	9 p. m.	4.5	420	14.7	6.3	3.6		..
24–30	3 a. m.	4.5	380	3.4	.0	14.5		100
	9 a. m.	4.5	520	17.7	1.1	16.2		100
	3 p. m.	4.5	530	11.3	.7	10.4		100
	9 p. m.	4.5	400	10.8	.0	12.0		100

TABLE 9.—RECORD OF THE OPERATION OF TANK A, MAY 21-NOVEMBER 1, 1915. (Continued).

Date.	Time of Filling	Period of Aeration. [Hours.]	Amount of Air. [Cu. ft.]	Raw. Nitrogen. [Parts per million.] Ammonia.	Effluent. Nitrogen. [Parts per million.] Ammonia.	Effluent. Nitrogen. Nitrite.	Effluent. Nitrogen. Nitrate.	Effluent. Stability [Per cent.]
Aug. 31–Sept. 6	3 a. m.	4.5	410	5.7	1.0	7.9		100
	9 a. m.	7.1	580	25.1	5.8	7.5		95
	3 p. m.	7.5	640	10.8	5 2	2.1		75
	9 p. m.	5.5	490	14.7	4.5	5.1		92
Sept. 7–13	3 a. m.	4.5	330	8.7	3.6	2.6		96
	9 a. m.	6.2	630	32.4	10.4	2.7		60
	3 p. m.	4.5	350	15.8	13.6	.0		28
	9 p. m.	4.5	320	17.1	12.6	.3		44
14–20	3 a. m.	6.2	410	3.9	2.6	2.6		90
	9 a. m.	4.5	430	21.8	12.9	.0		73
	3 p. m.	4.5	430	13.1	8 9	.1		80
	9 p. m	4.5	380	14.9	9 8	.8		63
21–27	3 a. m.	4.5	250	8.3	8.1	.3		60
	9 a. m.	8.8	1450	30.6	18.3	2 3		55
	3 p. m.	4.5	500	18 8	15.5	.3		22
	9 p. m.	4.5	360	20.9	15.9	.0		28
Sept. 28–Oct. 4	3 a. m.	17.0	1480	13.4	6.9	5 1		84
	9 a. m.	6.5	690	32.5	18.5	1.1		75
	3 p. m.	4.5	780	18.3	10.3	.0		30
	9 p. m.	4.7	580	22.1	12.2	1.3		51
SLUDGE ALONE AERATED FROM 3:30–8:00 a. m.								
Oct. 5–11	3 a. m.	9.6	1300	....	....	....		..
	9 a. m.	5.8	610	39.6	27.7	.1		23
	3 p. m.	4.3	600	21.1	16.2	.0		20
	9 p. m.	4.5	470	26.1	18.3	.0		16
12–18	3 a. m.	12.6	1800	....	....	....		..
	9 a. m.	4.6	650	41.6	28.0	1.0		38
	3 p. m.	4.9	630	21.5	19.4	.2		33
	9 p. m.	4.5	570	28.2	18.8	1.2		56
ALL SEWAGES AERATED.								
Oct. 19–25	6 a. m.	5.3	1110	8.8	6.9	5.1		100
	10 a. m.	5.4	850	40.0	25.4	1.5		76
	5 p. m.	5.7	670	21.6	18.1	.0		41
	12 p. m.	4.6	660	30.5	21.7	1.3		65
Oct. 26–Nov. 1	6 a. m.	4.4	1020	9.0	7.8	2.9		98
	10 a. m.	6.7	1530	38.2	20.8	2.1		78
	5 p. m.	4.7	900	19.2	13.4	.1		57
	12 p. m.	5.1	660	26.3	17.9	.2		55

was added at 3 a. m., and the sludge alone was aerated from 3:30 to 9:00 a. m. This procedure was followed from October 5-18, but no satisfactory effluents were obtained.

From October 19 to November 1, sewage was added four times a day, but the time of addition was changed from the previous schedule. The weak sewage added at 5:30 a. m. was easily nitrified and that added at 9:30 a. m. gave a fairly stable effluent with an excessive amount of air and a long period of aeration. Sewages added at 4:30 p. m. and 11 p. m. gave poor effluents, however, with normal amounts of air and a normal period of aeration.

Amount of air-diffusing area necessary. A comparative test was made in tanks C and D, to determine the relative efficiency of the diffusion area in these tanks. The bottom of tank C contains 3 square feet of Filtros plates for each 10 square feet of floor area; the bottom of tank D contains but one square foot. The tanks were operated from July 6-19 (see Table 10) under similar conditions. In each tank the sewage was changed 47 times, an average of four times a day.

The effluents from tank D were uniformly poorer than those from tank C. It is possible that the difference was caused by the fact that but 0.9 cubic foot of air per gallon was used with tank D, and 1.13 cubic feet per gallon was used with tank C. It is more probable that the poor results in tank D were caused by the insufficient amount of distribution area. The amount of air supplied to the sewage in tank D was always sufficient to keep the sludge well mixed with the sewage, but not much more air could have been used without excessive agitation of the sewage and sludge. The best results have uniformly been obtained with tank C. Results obtained with tank D were very unsatisfactory.

TABLE 10.—COMPARISON OF THE RESULTS OBTAINED BY AERATION OF SEWAGE WITH PLATE SURFACE IN TANK C THREE-TENTHS OF THE FLOOR AREA AND IN TANK D ONE-TENTH OF THE FLOOR AREA.

Number of Fillings.	Period of Aeration.	Air for 400 gals. sewage.	Raw.	Effluent.			
			Nitrogen. [*Parts per million.*]				Stability.
	[*Hours.*]	[*Cu. ft.*]	Ammonia.	Ammonia.	Nitrite.	Nitrate.	[*Per cent.*]
Tank C. 47	4.9	454	14.6	10.8	.5	1.4	50
Tank D. 47	4.9	360	14.6	12.1	.1	.5	18

A diffusion area covering three-tenths the floor surface gives much better results than a diffusion area covering either all, or one-tenth, the floor surface (see Table 10). This ratio might possibly be reduced to one-sixth or one-seventh the floor area without marked deterioration in the quality of the effluent but no tests were made of such areas.

The Filtros plates were very satisfactory for air diffusion. They distributed the air in fine bubbles, and gave no trouble through clogging or breaking. In large installations plates of uniform porosity must be used and the manufacturers are attempting to produce a more uniform grade of plates for use in sewage aeration. The plates must be set as nearly as possible at the same level, as a variation of one-fourth inch will cause uneven air distribution.

QUANTITY OF SLUDGE FORMED

In order to avoid loss of sludge during the removal of the effluent, several short lengths of 2-inch pipe were loosely threaded together so that they would collapse and one end was connected to the lower outlets of tanks A, B, and C. During aeration the open end of these pipes was held above the surface of the sewage by means of a chain. After the sludge had settled, the open end could be lowered to within a few inches of the sludge, and effluent could be drawn off without disturbing the sludge.

In order more surely to prevent loss of sludge a hollow cast-iron frame one foot square and 6 inches wide was screwed onto the free end of the collapsible effluent pipe in tank C. The sides of this frame were covered with a 16-mesh copper screen, through which the effluent had to flow. After this device had been installed a few determinations of the amount of sludge obtained were made in tank C.

A determination of the actual weight of sludge formed in 12 days was made. Prior to July 20, 1915, tank C had been filled 47 times, each time with an average of 435 gallons, or making a total of 20,400 gallons. After draining the effluent, the sludge was removed and placed on a small sludge-drying bed, 4 by 8 feet in plan. The sides of the bed were constructed of 12 by 2-inch boards. Coarse sand was placed in this frame to a depth of 8 inches and cheese-cloth was spread over the sand in order to avoid mixing sand with the sludge. Because of rains the sludge dried very slowly so that it was finally necessary to dry it on a steam bath. After drying it weighed 10,610 grams which is equivalent to 520 kilograms to 1,150 pounds per million gallons of sewage.

Compared with later results this value is high, perhaps because of the addition of sand and gravel from the sludge-drying bed.

Sludge was removed from tank C on November 5. Part of it was placed on the sludge bed, and the remainder on another bed made of crushed coal which was also covered with cheese-cloth. This sludge never did dry, because of rain, snow, and cold weather, and the weight of the dry sludge was not obtained. The experiments with sludge-drying beds were considered very unsuccessful since it was shown that the success of such a method of drying is dependent largely on weather conditions.

Tank C was operated from January 6-25, 1916, changing the sewage usually four times a day. On January 25, after the effluent had been removed, the amount of sludge was calculated. The solids in an aliquot portion of this sludge were determined and the amount of dry sludge then calculated.

Fifty-four additions of sewage of 400 gallons each and three additions of 200 gallons each had been made. The data and calculations are given below.

Weight dry sludge.

Depth of sludge in tank C	30 inches
Quantity of sludge in tank C	22 cubic feet
Weight of sludge in tank C	1,386 pounds
Per cent of solids in sludge	1.17 per cent
Weight of dry sludge	16.2 pounds
Total volume of sewage added	22,200 gallons
Amount of dry sludge per million gallons (calculated)	750 pounds

Tank C was operated in a similar manner from March 9-23, 1916. The same calculations were made as in the previous case.

Weight dry sludge.

Depth of sludge in tank C	30 inches
Quantity of sludge in tank C	22 cubic feet
Weight of sludge in tank C	1,386 pounds
Per cent of solids in sludge	0.98 per cent
Weight of dry sludge	13.6 pounds
Total volume of sewage added	18,400 gallons
Amount of dry sludge per million gallons (calculated)	740 pounds

The limited data obtained from the three experiments just described indicated that from 740 to 1,150 pounds of dry sludge may be obtained per million gallons of Champaign sewage.

COMPOSITION OF SLUDGE

Content of nitrogen. If activated sludge is to be used as a fertilizer its most important constituent is nitrogen. Three series of determinations have been made of the increase in the content of nitrogen during the initial accumulation of activated sludge in tank C.

The first series of samples was collected from tank C during the period from October 4 to November 4. The sewage was changed three times a day for the first three weeks, with five hours' daily aeration of the sludge alone; after that four changes of sewage per day were made. An average of 800 cubic feet of air per gallon and 4.9 hours' aeration were used during each aeration period. The strength of the sewage treated was normal. Thirteen samples of sludge were taken at intervals, filtered on a Büchner funnel, dried on the steam bath, and the amount of nitrogen determined (see Table 11).

TABLE 11.—CONTENT OF NITROGEN IN SAMPLES OF SLUDGE COLLECTED FROM TANK C, OCTOBER 4 TO NOVEMBER 5, 1915.

Sample No.	Date.	Time.	Number of Fillings.	Average. Air for 400 gals. sewage.	Average. Period of aeration.	Average. Stability.	Nitrogen in sludge.
		[Days.]		*[Cu. ft.]*	*[Hours.]*	*[Per cent.]*	*[Per cent.]*
1	Oct. 4	0	1	750	4.0	0	3.6
2	Oct. 5	1	4	520	4.5	5	4.4
3	Oct. 6	2	7	380	4.5	8	4.2
4	Oct. 7	3	10	630	4.5	10	5.3
5	Oct. 8	4	13	510	4.8	15	4.9
6	Oct. 11	7	18	610	5.7	7	5.2
7	Oct. 13	9	24	660	4.6	13	4.8
8	Oct. 19	15	36	920	4.8	54	5.2
9	Oct. 25	21	53	1340	5.5	90	3.9
10	Oct. 27	23	61	1070	4.6	100	4.1
11	Oct. 28	24	65	690	4.5	96	4.1
12	Nov. 2	29	82	1080	5.6	100	4.0
13	Nov. 5	32	89	1280	5.6	99	4.1
Average (excluding first day)				800	4.9	...	4.5

Interesting features noted were the high nitrogen (3.6 per cent) in the sludge after the first aeration, the rapidity with which it increased, reaching its maximum (5.3 per cent) in three days, and the variations in the content of nitrogen. Simultaneous with the decrease in nitrogen in sample 9 there was a considerable increase in the time of aeration and in the amount of air which had been applied. This suggests that the content of nitrogen of the sludge is affected by the amount of aeration; that longer aeration decreases the percentage of nitrogen present as well as the amount of sludge.

The second series of samples was collected from tank C from January 6-25. During this test the sewage was changed 57 times, usually four times a day. From the seventh day, January 13, until 8 a. m. on the tenth day, January 17, no sewage was added, since the sewage had backed up in the sewer to such an extent that it could not be opened to clean out the clogged intake pipe. During this time the sludge alone was aerated. An average of 590 cubic feet of air per gallon and 5.1 hours' aeration were used during each aeration period. The raw sewage applied was very dilute and contained considerable grit. Determinations of ammonia nitrogen, nitrite and nitrate nitrogen and suspended matter were made on each raw sewage and effluent. The nitrogen values of the sludge showed the same characteristics (see Table 12) as were shown in the first series, with the exception that the decrease in nitrogen on prolonged aeration was not so marked.

The third series of samples was collected from tank C from March 9-23. An average of 700 cubic feet of air per gallon and 4.9 hours' aeration were used during each aeration period. Determinations were made of ammonia nitrogen, nitrite and nitrate nitrogen, stability,

TABLE 12.—CONTENT OF NITROGEN OF SAMPLES OF SLUDGE COLLECTED FROM TANK C, JANUARY 6-25, 1916.

Sample No.	Date.	Time.	Number of Fillings.	Average. Air for 400 gals.	Average. Period of Aeration.	Nitrogen in Sludge.	Remarks.
		[Days.]		[Cu. ft.]	[Hours.]	[Per cent.]	
1	Jan. 6	¼	1	890	5.5	3.40	Very much.
2	7	1	5	580	4.4	3.80	Rain, dilute sewages.
3	8	2	8	370	5.8	4.20	
4	10	4	14	700	6.8	4.60	
5	12	6	21	540	5.1	4.70	
6	13	7	25	620	4.5	4.90	
7	17*	10¾	28	500	5.0	4.60	*Sludge alone aerated 74 hours before this sample was taken.
8	17	11	29	630	5.0	4.90	
9	18	12	33	1010	4.5	4.90	
10	19	13	37	570	4.5	4.80	
11	20	14	41	520	4.5	5.10	
12	21	15	45	460	4.5	4.90	
Average (excluding first day)............				590	4.9	4.6	

suspended matter, and the total organic nitrogen of the raw and filtered sewage. Sludge was collected and analyzed as before with additional determinations of phosphorus (P_20_5), carbon (C) and fat. Carbon was determined by fusion of the sample in a bomb with sodium peroxide, thus converting all carbon into carbonate. The fusion was dissolved in water, carbon dioxide was liberated by HCl, and measured in the Parr apparatus. Total carbon was calculated from the data thus obtained (see Table 13). .The same rapid increase in nitrogen in the first few days was very apparent. The effect of long aeration was shown more markedly, the content of nitrogen being reduced from 5.7 per cent in sludge 7 to 4.9 per cent in sludge 8.

Under average conditions 5.1 per cent nitrogen was obtained in the sludge.

The content of nitrogen of the sludge increased very rapidly, the increase during the first day amounting to from 0.4 to 1.5 per cent.

TABLE 13.—ANALYSES OF SAMPLES OF SLUDGE COLLECTED FROM TANK C, MARCH 9-23, 1916.

Sample No.	Date.	Time.	Number of Fillings.	Average. Air for 400 gals.	Average. Period of aeration	Nitrogen in sludge.	Carbon in sludge.	Ratio C:N.	P_2O_5 in sludge.	Fat in sludge.
		[Days.]		[Cu. ft.]	[Hours.]	[Per cent]	[Per cent]		[Per cent.]	[Per cent]
1	March 9	¼	1	460	5.0	2.94	44.2	15.0	1.70	22.9
2	10	1	5	560	4.4	4.29	43.8	10.2	2.27	....
3	13	4	14	690	6.5	4.41	42.4	9.6	2.66	18.1
4	14	5	18	480	4.5	5.03	40.1	8.0	2.77	16.4
5	15	6	22	640	4.5	5.08	40.0	7.9	3.32	14.6
6	16	7	26	670	4.5	5.57	40.9	7.3	3.46	13.0
7	17	8	30	800	4.5	5.66	40.4	7.1	3.33	11.4
8*	20	11	35	930	6.2	4.93	38.6	7.8	2.77	13.0
9	21	12	39	620	4.5	5.30	39.0	7.3	2.88	12.1
10	22	13	43	930	4.5	5.13	....	...	3.03	10.9
11	23	14	47	850	4.5	5.52	....	...	3.11	9.6
Average, (excluding first day).				700	4.9	5.10	41.0	8.1	2.96	13.7

*Sludge alone aerated.

After the first day it fluctuated between 3.8 per cent and 5.7 per cent and was decreased by excessive aeration or by large quantities of grit.

Two reasons have been offered to explain the high nitrogen value of activated sludge.

The first explanation is that the colloidal matter of sewage is retained in the sludge and incorporated with it. It has been shown experimentally that the nitrogen in activated sludge is equivalent to the amount present in the suspended matter of the sewage from which the sludge was formed. In the third series (see Table 13) determinations of suspended matter in the raw sewage and total organic nitrogen in the raw and filtered sewage were made. The nitrogen in the suspended matter was equal to the difference between the nitrogen in the filtered sample and that in the unfiltered sample. The average value of the nitrogen in the suspended matter in the 46 raw sewages applied was 5.15 parts per million. The average amount of suspended matter was 121 parts per million. Therefore, 4.2 per cent of the suspended matter was nitrogen.

Reported analyses of sludges obtained from normal sewages by plain sedimentation usually give less than 3 per cent for the content of nitrogen.[10, 19] Because of this low nitrogen value such sludges are considered of little value as fertilizers.

It is probable that the coarser suspended matter, which settles out to form such sludge, is low in nitrogen, while the finely divided, colloidal matter is relatively high in nitrogen. This colloidal matter is not removed from the first effluents, and accordingly the sludge at the beginning of operation is low in nitrogen. As more colloidal matter is removed, the nitrogen increases finally reaching a maximum when all of the colloidal matter is retained in the sludge.

Lederer[17] has shown that the colloidal matter is more unstable than the "settleable solids," and this fact indicates that it is higher in nitrogen.

The second explanation for the high nitrogen value of activated sludge was suggested by Adeney.[1] He has shown that oxidation of the organic matter of sewage proceeds in two steps, first, the fermentation of carbonaceous substances, and second, the oxidation of nitrogenous substances. The reaction,

carbonaceous matter + oxygen = carbon dioxide.

proceeds more rapidly than

nitrogenous matter + oxygen = nitrate nitrogen.

It is probable that the high nitrogen value of activated sludge is obtained by both the methods indicated—that is, by complete removal of suspended matter, and by the "burning out" of carbon.

Content of carbon. The contents of carbon of the sludges obtained in the third series during the first days (see Table 13) were higher than those for the later sludges. The ratio of C : N decreased greatly. In the first sludge the ratio was 15.0, but after a week's operation it had dropped to 7.2. This agrees with the theory that the increase in the proportion of nitrogen in the sludge is caused by the decrease in the carbon.

Content of phosphorus. The value of activated sludge as a fertilizer may depend to some extent upon its content of phosphorus. Phosphorus in a series of eleven sludges follows the same variations as nitrogen (see Table 13). The same theories that account for the accumulation of nitrogen in the sludge are also applicable to phosphorus.

Proportion of suspended solids retained. During the test from January 6-25, 16.2 pounds of dry sludge were recovered from 22,200 gallons of sewage. The average quantity of suspended matter in the raw sewage was 104 parts per million. Since the effluent was passed through a 16-mesh screen it was approximately free from suspended matter. All of the suspended matter of the raw sewage must have remained in the tank, or must have been removed by liquefaction of the sludge. If all remained 22,200 gallons of sewage containing 104 parts per million suspended matter should have given 19.1 pounds of dry material. Since only 16.2 pounds or 85 per cent were recovered, 2.9 pounds or 15 per cent must have been liquefied.

During the test from March 9-23, 13.6 pounds of dry sludge were recovered from 18,400 gallons of sewage. The average quantity of suspended matter in this sewage was 121 parts per million, or equivalent to 18.4 pounds of dry material. The 13.6 pounds then represents a recovery of 74 per cent.

It is interesting to compare this removal of suspended solids with that obtained by plain sedimentation. It has been found that a certain amount of the finely divided suspended matter of sewage can not be removed even with prolonged sedimentation. This suspended matter is in a colloidal state, forming a hydrogel which is not precipitated by plain sedimentation.

Fuller[12] states that only 70 per cent of the suspended matter in the sewage of Columbus, Ohio, could be removed by plain sedimentation. The remaining 30 per cent passed off in the effluent unless removed by special treatment.

The removal of this finely divided suspended matter is one of the most advantageous features of the activated-sludge process. The effluents are practically free from colloidal matter and nearly 100 per cent of the suspended solids is removed.

Activated sludge has been found valuable as a fertilizer.[4] It is undoubtedly worth recovering because of its high content of nitrogen and phosphorus. This fact gives a different aspect to the question of sludge disposal. In former processes, a small amount of sludge was desired and all possible means for liquefaction were used. In the activated-sludge process all possible means should be used to recover the suspended matter. A recovery of 75-85 per cent is desirable and even higher yields may be possible.

DEWATERING OF ACTIVATED SLUDGE

As the sludge was taken from the tanks it had the appearance of a flocculent precipitate of ferrous-ferric hydroxide. It usually contained 98-9 per cent of water and on standing settled to some extent. After three or four hours, however, the sludge became filled with bubbles of gas from anaerobic decomposition, which caused it to rise to the surface. In this condition it contained 97-8 per cent of water and had the appearance of a hydrogel. Upon further standing it became septic and very colloidal.

The simple sludge-drying bed of sand and gravel was constructed as described on page 30 for dewatering the sludge. In warm, dry weather the bed gave fairly satisfactory results. The sludge dried to a tough, leathery consistency, and had to be dried further on the steam bath before it could be ground. If a rain occurred while the sludge was on the bed, water would not filter through the partially dried sludge but accumulated on the surface of the bed. This had to be removed by decantation or by evaporation.

In the winter it was impossible to dry any sludge on the bed. Alternate freezing and thawing prevented drainage through the sand, and snow and rain kept the sludge wet.

In order to obtain a sludge in marketable condition some degree of heat drying is necessary. The amount of fuel required for drying varies with the amount of water contained in the sludge. Grossman[13] has derived formulae and compiled tables showing the amount of water that must be evaporated from sludges containing varying amounts of water.

If x is the percentage of solid matter and y the amount of water in tons to be evaporated to yield one ton of dry sludge, then

$$y = \frac{100}{x} - 1.$$

If m is the price of coal in dollars per ton, n is tons of water evaporated per ton of coal, and z = cost of drying sludge containing x per cent of solid matter to dryness, then

$$z = \frac{m}{n}\left(\frac{100}{x} - 1\right).$$

Assuming that one ton of coal will evaporate six tons of water from sludge, and that the cost of coal is $1.25 per ton, he has calculated the cost of drying sludges containing from 5 to 50 per cent of solid matter (see Table 14).

TABLE 14.—CALCULATED COST OF COAL REQUIRED TO PRODUCE ONE TON OF DRY SLUDGE FROM SLUDGES CONTAINING 5-50 PER CENT OF SOLID MATTER.

Solid matter. [*Per cent.*] (X).	Amount of water to be evaporated. [*Tons.*] (Y).	Cost of coal required.[a] (Z).
5	19	$3.96
10	9	1.88
15	5.7	1.17
20	4	.84
25	3	.63
30	2.3	.49
35	1.9	.39
40	1.5	.31
45	1.2	.25
50	1.0	.21

[a]Calculations based on assumption that one ton of coal at $1.25 will evaporate six tons of water from sludge.

It will not pay to reduce the water in the sludge by mechanical means to less than 70 per cent, if the sludge must be subsequently dried by heat. A sludge with 80 per cent of water could be very economically dried but satisfactory results might be obtained for sludges containing between 70 and 80 per cent of water.

Precipitants. In order to reduce the water in the sludge to such an extent that drying by heat could be used economically, the effects of several precipitating agents upon a fresh sludge containing 98 per cent of water were studied (see Table 15).

Sodium phosphate is apparently a very good precipitant but the results obtained with 5 grains per gallon even after 24 hours' settling do not warrant its use.

The sludge contained two grams of solids and 98 grams of water. If the volume of water in the sludge is reduced 45 per cent by the precipitant there will be 2 grams of solids in the remaining 55 grams

TABLE 15.—THE EFFECT OF CHEMICAL PRECIPITANTS UPON ACTIVATED SLUDGE.

Precipitant.	Per cent reduction in volume of sludge after settling for		
	2 hours	3 hours	4 hours
Sodium Phosphate Na_3PO_4 5 grains per gallon	15	20	45
Lime and Iron $CaO + FeSO_4$ 5 grains per gallon	15	18	44
Lime CaO 10 grains per gallon	12	16	41
$Al_2(SO_4)_3$ 5 grains per gallon	8	12	35
Control	6	10	26

of sludge, and the water in the sludge has only been reduced from 98 to 96.4 per cent.

It is apparently futile to attempt to reduce the content of water of sludge by precipitants. Precipitants may alter the physical character to such an extent that it may be filter-pressed or dried more easily. If this is possible precipitants must be chosen that will add to the value of the dried sludge when used as a fertilizer.

Limestone and rock phosphate, substances which do not react with the substances dissolved in water to form a floc, added in the same manner had no noticeable clarifying or coagulating effect.

Filter-presses. Attempts were made to dewater the sludge by filter-pressing. The smallest Sperry filter-press was used. This was the usual hollow-frame press, into which the sludge was fed from a drum under air pressure of 70 pounds. Satisfactory results were not obtained. Filter-pressing the sludge after the addition of lime was next tried because of the cheapness of lime, and its use in de-odorizing septic sludge.

On February 17, 17,000 grams of sludge were treated with 20 grains per gallon of lime. After pressing for 4 hours at 70 pounds no cake was formed and only a slimy mass remained in the frame.

These experiments and a number of others which followed showed that it was practically impossible to obtain a good cake either with or without the addition of lime. The filter-cloth becomes clogged with an impervious layer of sludge, and at 70 pounds' pressure no more water could be forced through it. Lime does not seem to change the character of the sludge so that it will not clog the filter-cloth.

Filtros-plate filters. Two 6-inch Filtros plates cemented into a frame were lowered into the sludge and suction applied to an outlet between the plates. A very thin film of solid matter soon covered the plates, and after it had been formed no more water could be drawn through it. This device, intended to stimulate the action of a large-scale device called the "Robacher wheel," gave only unsatisfactory results.

Centrifuges. Two small centrifuges, one of the low-speed, basket type, the other of the high-speed, bottle type, were available for the experiments.

The basket of the low-speed machine was 8 inches in diameter and 6 inches deep, and the periphery was perforated with numerous holes one-sixteenth of an inch in diameter. The machine was lined with a strip of muslin cloth covering the holes. Approximately 3,500 grams of 98-per cent sludge were put into the centrifuge and, after 15 minutes, 700 grams of 91-per cent sludge were obtained. The effluent was very dark-colored, but the cake was firm and of uniform consistency.

The high-speed, bottle-type machine reduced the moisture from 98 per cent to 92 per cent in three minutes and gave a clear supernatant liquid.

Considering the crudeness of the basket-type centrifuge used, the results obtained were promising, and such an apparatus, in a more efficient form, should reduce the water in the sludge to 80 per cent. In order to be economical, an automatic arrangement for removing the cake must be provided. Such machines are not made in this country, but have been in use in Germany for a number of years.

The most successful apparatus of this type is the Schafer-ter Meer centrifuge[14] built by ter Meer at Hanover according to the design of Schafer, city engineer of Frankfort. This machine consists of a revolving drum mounted on a hollow vertical axis and surrounded by an outer casing.

The wet sludge enters the center of the revolving hollow axis through an overhead inlet pipe while the machine is in motion. Six radial compartments of 3-liters capacity are attached to the axis, and the inner and outer peripheries of these compartments are closed and opened by slide valves controlled by oil under pressure. On the sides of the compartments are numerous slots 10 by 0.5 millimeters.

The operation is intermittent. Sludge is admitted from the hollow shaft. The heavier particles are thrown against the outer part of the cells and the water escapes through the slots in the sides. The cells are filled with sludge in 2-3 minutes. The inner valves are then closed automatically and after a number of revolutions of the drum the outer valves are opened. The dried sludge is thrown from the cells and falls down onto a belt conveyor. A star-shaped scraper mechanically cleans the sides of the cells after the sludge has been thrown out. This entire cycle requires but 2½-3½ minutes and the period for a dilute sludge is somewhat longer than for a more concentrated one. The drum makes 750 revolutions per minute.

The apparatus will treat approximately 4 cubic yards, or 6,800 pounds of a 92-per cent sludge per hour. The discharged sludge averages 60-70 per cent water, and is crumbly and odorless, except in very warm weather, when a slight odor is noticeable. The effluent is turbid and must be passed through sedimentation basins in order to give a clear liquid.

The machine uses 6.4 kilowatts, and the cost including depreciation of producing one ton of dried material (60-70 per cent of water) is $0.36. Each machine costs $5,500.

If such machines be tried out on a large scale they may be found to be applicable to the drying of activated sludge.

The economic success of the activated-sludge process will depend to a great extent on the solution of the problem of drying the sludge cheaply and easily. Although the disposal of the sludge has been the unsolved problem of present-day methods of sewage disposal, it is very likely that an effective method of dewatering activated sludge will be found. Its value as a fertilizer offers a greater incentive for its recovery than for recovering other kinds of sewage sludge. With nitrogen at 20 cents a pound, a sludge containing 5 per cent of nitrogen in an available form should be worth $20 a ton. Experiments by Bartow and Hatfield[4] have shown that the nitrogen is very available and that activated sludge may be considered at least as a medium-grade fertilizer. Considering this fact, it should not be classed in the same category as septic-tank sludge, Imhoff-tank sludge, and other sewage sludges, but should be classed with much higher grade materials such as fish-scrap, tankage, and dried blood. If some satisfactory method of reducing the moisture to 70-80 per cent is developed, final drying may certainly be carried out by some form of hot-air dryer.

COST OF THE ACTIVATED-SLUDGE PROCESS

The cost of constructing and operating activated-sludge plants has not been considered a part of this investigation, which has been confined more or less exclusively to the phases of chemical and biological interest and significance. The data which have been presented on such features as the accumulation of sludge, the amount of diffusion area required, the amount of air necessary, and the amount of nitrogen in the sludge, are of interest and value to the designer and operator of large-scale plants. Cost data in order to have the proper weight and significance must be secured by operation on a large scale.

A continuous-flow plant, having an estimated capacity of 200,000 gallons a day, has been built by the State Water Survey for the purpose of securing such data.

A plant with an estimated capacity of 2,000,000 gallons a day has been constructed at Milwaukee, Wis., and was operated during the winter of 1915-16.[15]

At Cleveland, Ohio, a plant with an estimated capacity of 1,000,000 gallons a day was put into operation during the latter part of January, 1916.[14]

Operation of these plants will determine whether or not the activated-sludge process is a success financially.

SUMMARY

1. In the aeration of sewage there is almost quantitative oxidation of ammonia nitrogen to nitrite nitrogen followed by oxidation to nitrate nitrogen. From ten to twenty days are required. In the aeration of sewage in contact with activated sludge, ammonia nitrogen is oxidized to nitrate nitrogen in from four to five hours. Nitrite nitrogen is evidently oxidized to nitrate nitrogen almost as rapidly as it is formed.

2. Satisfactory activated sludge can be obtained with six-hour aeration periods without complete nitrification from the beginning of the operation.

3. In a small tank the equivalent of 1,300 pounds of dry sludge per million gallons of strong sewage was obtained. In larger tanks 740 to 1,150 pounds of dry sludge per million gallons of average sewage were obtained.

4. In the presence of 25 per cent of sludge, weak sewage was well nitrified in four hours with one cubic foot of air per gallon of sewage. Normal sewage required 4-5 hours aeration and 1.3 cubic feet of air per gallon of sewage. Strong sewage required more than 5 hours' aeration and more than 1.5 cubic feet of air per gallon of sewage.

5. Better results were obtained when one-third of the floor surface was covered with porous plates than when all, or one-ninth of the floor surface, was covered.

6. The nitrogen in the sludge increases by from one-half to one and one-half per cent per day until an average of 5.1 per cent of

nitrogen is obtained. Excessive aeration decreases both the total quantity of the sludge and its percentage of nitrogen.

7. The content of phosphorus pentoxide (P_2O_5) varies in the same way as the nitrogen, reaching an average at about 3 per cent.

8. Dewatering the sludge is a problem which has not yet reached a satisfactory solution, although small-scale experiments with centrifuges have given promising results. It has been practically impossible to obtain a solid cake by filter-pressing the activated sludge, and experiments with precipitants and Filtros-plate filters also gave unsatisfactory results.

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