SEWAGE WORKS JOURNAL

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Special Features

The Activated Sludge Process:

Activated Sludge Operation—Pearse and Committee

Operation of New York Plants—Gould

Step Aeration—Fair and McKee

Diffuser Plate Cleaning—Wirts and Schade

Research on Guggenheim Process—Phelps and Bevan

Operation Costs in Illinois—Babbitt and Farnsworth

Chlorine Priorities—See P. 218

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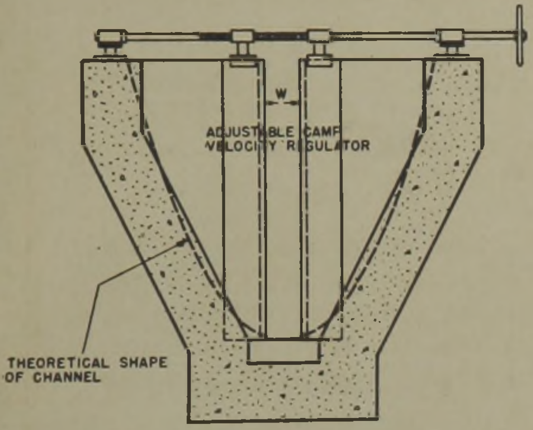

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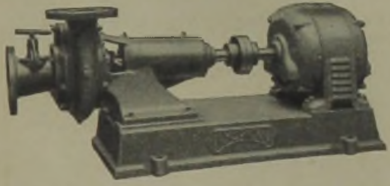

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3. Eliminates "Dirty Work" in operating sludge pumps.
4. Dependable, continuous service.

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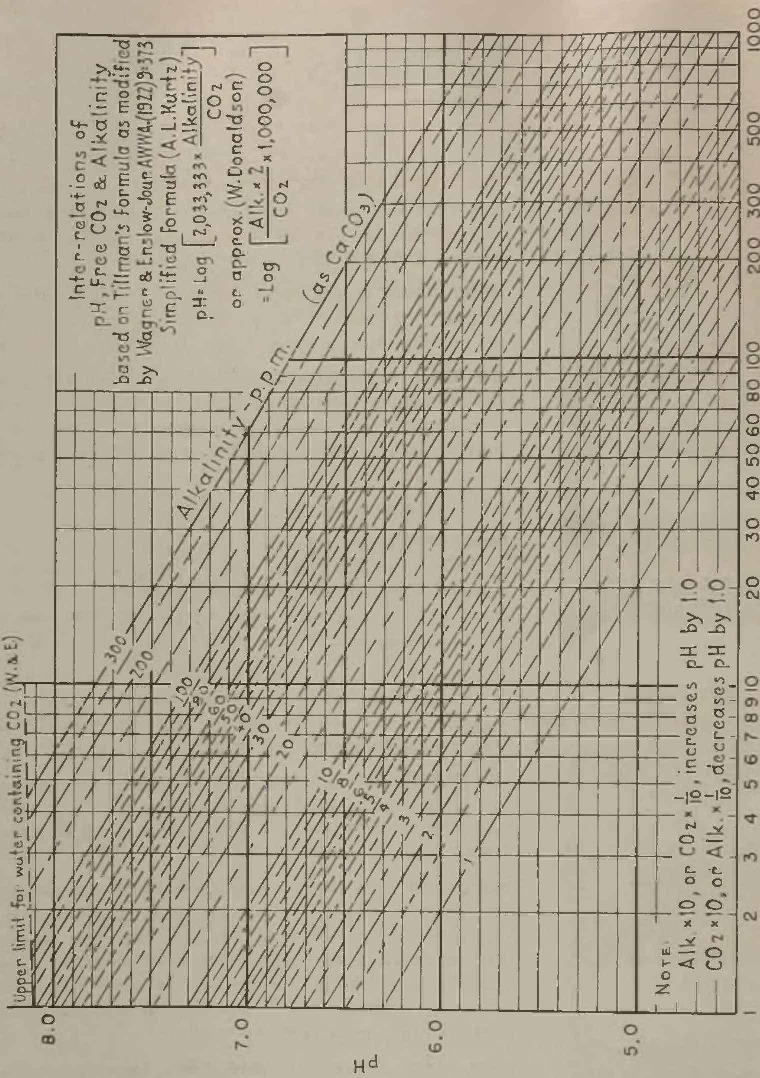

Inter-Relations of pH, Free CO_2 and Alkalinity

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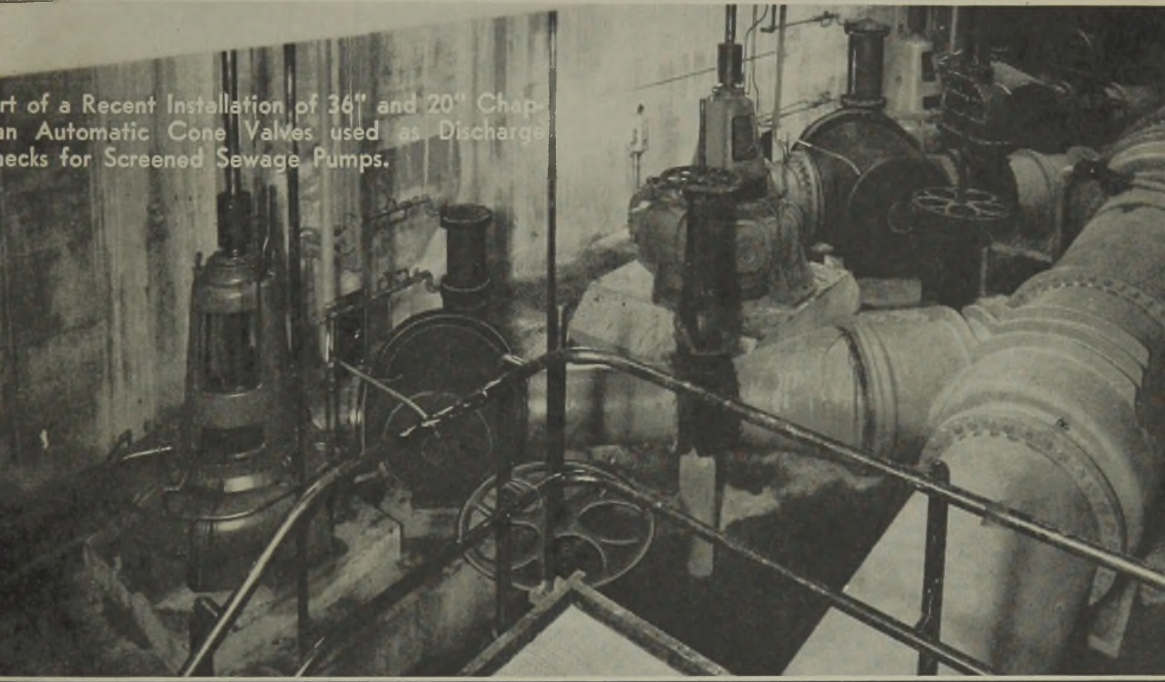
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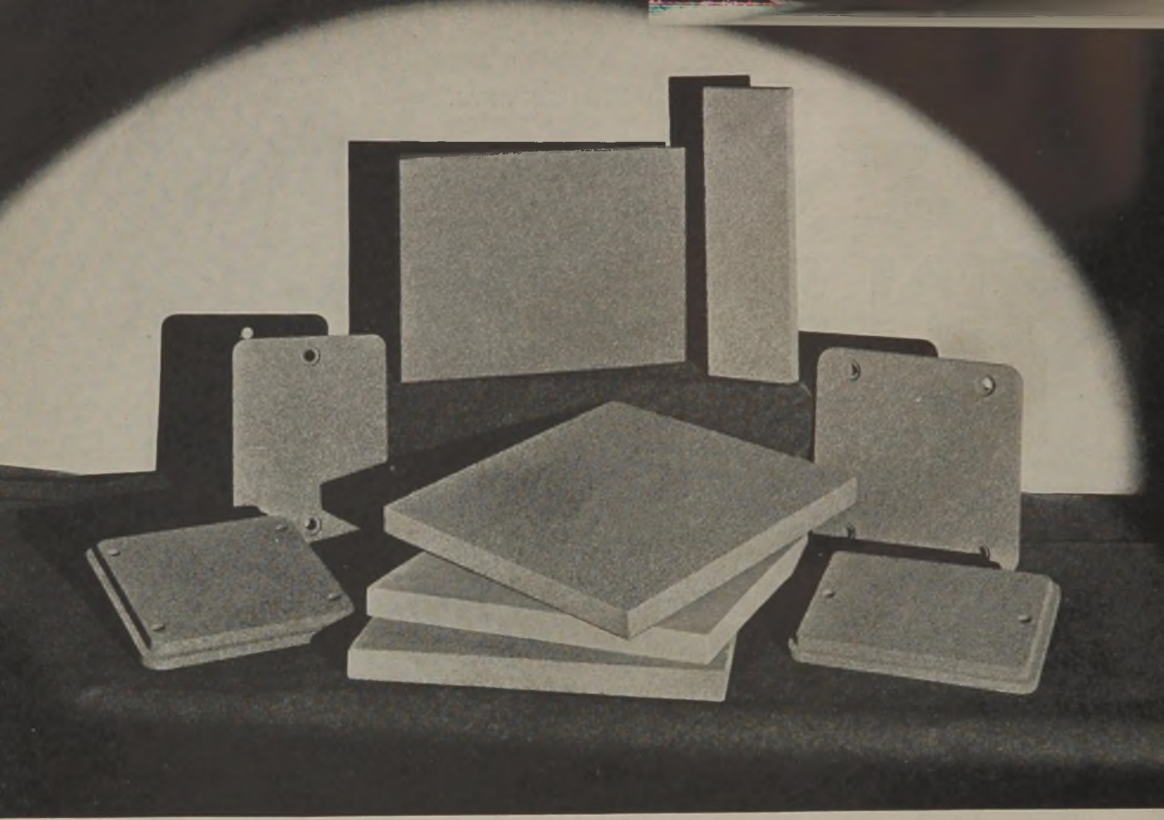
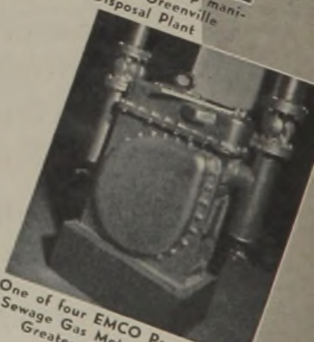


Nordstrom Valves— EMCO Meters *selected for*

GREATER GREENVILLE, S. C. SEWAGE DISPOSAL PLANT

Nordstrom Valves on pump manifolds in Greater Greenville Sewage Disposal Plant



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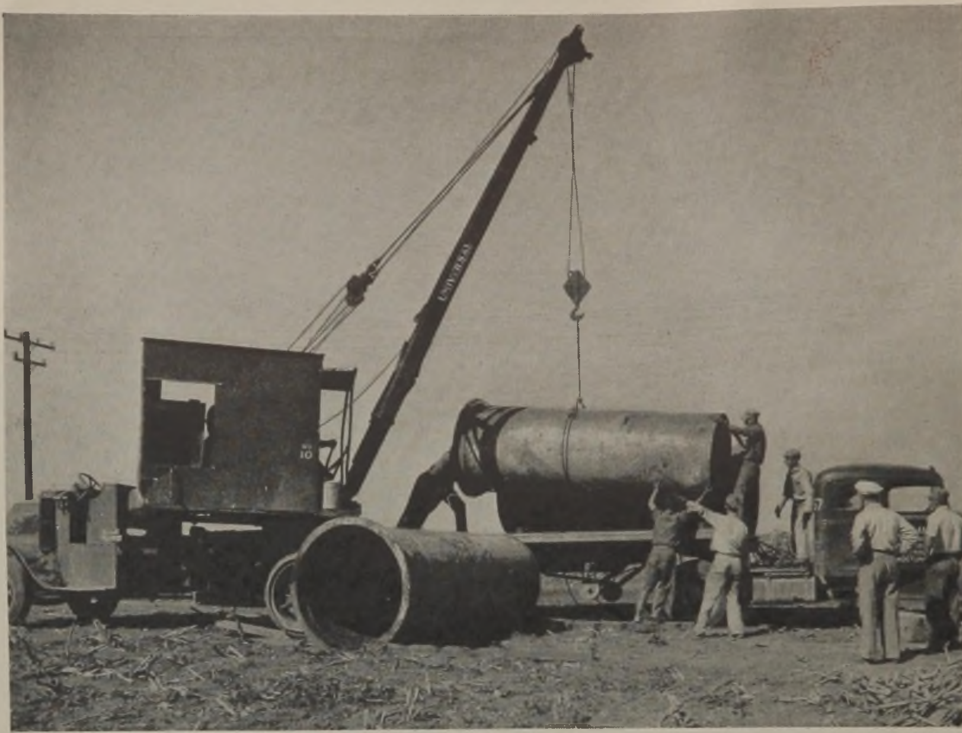
Battery of Nordstrom Valves in pit at Greater Greenville Sewage Disposal Plant

EMCO Pressed Steel Meters measuring sewage gas on Nordstrom Valve controlled lines in Greater Greenville Plant



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Plant Operation

THE OPERATION AND CONTROL OF ACTIVATED SLUDGE SEWAGE TREATMENT WORKS

REPORT OF COMMITTEE ON SEWAGE DISPOSAL AMERICAN PUBLIC HEALTH ASSOCIATION PUBLIC HEALTH ENGINEERING SECTION *

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The purpose of this Committee report, entitled "The Operation and Control of Activated Sludge Sewage Treatment Works," is to assemble available data on the operation and control of activated sludge sewage treatment works. No original research has been attempted. The thanks of the Committee are gratefully given to the various sewage works operators and municipal officials who have furnished data.

Since Ardern and Lockett (1) discovered activated sludge in 1913, much attention has been paid to the development of the engineering phases of the process and considerable research has been conducted on the theory of the process and its limitations. Little, however, has been published by plant operators on the control and the manipulation of activated sludge plants. What there is in the United States is scattered through the literature and in the offices and the laboratories of over two hundred sewage plants.

The Committee has endeavored to give a brief summary of operating practice, as exemplified at a number of sewage plants where complete records are kept, in the hope that others will furnish information from a wider group of plants for the compilation of a more exhaustive report.

BIBLIOGRAPHY

A bibliography of the literature from 1911 to 1920 was prepared by J. E. Porter (2) covering the period just prior to the operation of the

* Presented at the Atlantic City Meeting of the A. P. H. A., Oct. 14, 1941. Released by courtesy of the A. P. H. A.

Milwaukee plant. The Committee had hoped to supplement this bibliography but has concentrated its efforts on the more limited operating problems. From the standpoint of design, recent papers by Freese (3) and Regester (4) are of interest.

Basic Concept

The basic feature of the activated sludge process is the sludge that is produced. This sludge is derived from previous aerations of sewage in contact with accumulated sludge, which is settled out and returned to the incoming sewage. Such a mixture is commonly called the "mixed liquor" and is aerated and then settled. The purified effluent flows away and the wet sludge is returned to the inlet end of the aeration tanks to repeat the process.

The development of such a simple concept to a modern activated sludge plant was a process of evolution carried out by the practicing engineers in various parts of the world. The earliest tests were on a fill-and-draw basis. However, for large scale operations such procedure was impracticable. Hatton and Ferebee at Milwaukee, Wis., followed by Sands at Houston, Tex., showed how to design and operate a practicable continuous-flow process.

Activated Sludge Theory

In reviewing the activated sludge theory, Edwards (5) states that the activated sludge process proceeds in at least three stages—clarification, reactivation, and nitrification. The first stage is mainly physicochemical in nature, though biological action is necessary, whereas the second and third stages are largely biological.

Ruchhoft, Butterfield, McNamee, and Wattie (6) describe clarification as the removal of carbonaceous and nitrogenous organic matter in all states of dispersion (suspension, colloidal, and true solution) from sewage by sludge as a result of coagulation, adsorption, and other mechanisms. Clarification is rapid, usually occurring within 30 to 40 minutes, followed by reactivation or restoration of the process of clarification. In experiments, from 80 to 95 per cent of the total carbonaceous B.O.D. is removed in 5 hours. The rate of removal is very high for the first half-hour, but action continues for 1½ to 3 hours. Thus the activated sludge process may actually oxidize 25 to 30 per cent of the carbonaceous B.O.D. in 30 minutes, and from 30 to 60 per cent in 5 hours.

Attempts to divide the process into definite stages have had but little success, although Butterfield, Ruchhoft, and McNamee (7) have isolated bacteria from activated sludge which form massed flocs and exhibit both adsorption and oxidation under pure culture condition in a liquid medium.

Fundamentals of Biochemical Oxidation.—In studying the fundamentals of the biochemical oxidation process, Butterfield and Wattie (8) indicate tentatively that:

1. Under natural conditions oxidation does not occur in the absence of living biological agents.

2. Oxidation takes place only as a result of the metabolic activity and proliferation of living bacteria and is proportionate, though perhaps not directly, to the number of new cells produced.

3. The oxidation occurring during any time interval is proportional to the amount of food or organic material utilized by the bacteria.

Their conclusion is that the rate of oxidation of bacterial food during the earlier hours of incubation is dependent on the initial number of bacteria and is influenced by the degree of dispersion of bacteria or the bacterial flocs.

Enzymes.—Wooldridge and Standfast (9, 10) present evidence that a most important factor in the biological oxidation of sewage is a series of catalyzed oxidation-reduction reactions determined by bacterial enzymes present in either living or dead cells or liberated by them into the fluid of the reacting system. The oxidation of sewage depends generally on the presence of certain oxidation enzymes (dehydrogenases and oxidases) of micro-organisms. These enzymes may be effective whether the organisms are alive or dead, provided the enzymes are not destroyed. This statement is confirmed by Wooldridge and Corbett (11), Dickinson (12) and Ingols (13). On this basis the adsorption of substances by activated sludge depends on enzymes. A floc may be considered a gelatinous matrix surrounded by a layer of enzymatically active material.

For oxidation-reduction, Ingols (13) considers enzymes to be essential. The activity of the activated sludge depends on the concentration of the enzymes. The rate of activity depends on the temperature, amount of oxygen supplied, the pH of the medium, and the type of food. Nitrifying organisms are active only in an excess of both free ammonia, oxygen and alkalinity. The enzyme concentration of an activated sludge-sewage mixture may be 60 to 120 times that of sewage alone. Enzymes increase with heavy sewage load and decrease with over-aeration. Their activity increases between 10 deg. and 37 deg. C. A temperature of 45 deg. C for 10 min. retards action. A temperature of 55 deg. C for 10 min. destroys enzymes. Enzymes are active over a range of pH from 6 to 9.

Other Theories.—Theriault (14) suggests that the action of activated sludge is akin to zeolitic action, and recently Mihaeloff (15) claims that particles of calcium carbonate are necessary for the activity of activated sludge. The trend of opinion, however, is that the process is biochemical.

Oxygen Absorption in Theory and Practice

Heukelekian and Ingols (16) find that activated sludge possesses the potentiality and mechanism of rapid oxidation. To bring the 1937 review of Theriault (14) up to date, they note that previous investigators never drew the obvious conclusion that, during the so-called clarification stage, maximum oxidation was also taking place, although the results pointed in that direction.

Various observers have indicated that the oxygen consumption of activated sludge may range from 26.6 to 110 p.p.m. per hour (17, 18, 49), depending upon the amount of dry solids in the sludge and its volatile content.

Grant, Hurwitz, and Mohlman (17) show that the rate of oxygen absorption in mixtures of activated sludge and sewage is highest at the beginning. The rates tend to attain a straight line relation with increasing time of aeration, especially with the higher concentration of sludge in the mixture. These investigators emphasize the effect of sludge concentration in the mixture on the rate and absolute amount of oxygen absorption, from the standpoint of supplying the demand by adequate aeration, and they show that the oxygen absorbed by the sewage component of an activated sludge mixture is greater in the presence of lower concentrations of sludge than in the presence of higher concentrations. The maximum demand was 10 p.p.m. in two hours in the presence of 920 p.p.m. of suspended solids in the sludge. Theriault and McNamee (18) indicate that activated sludge, to which no sewage has been added, when reaerated, absorbs oxygen faster during the first hour than subsequently.

Kessler and Nichols (19) report that the oxygen consumption is greater for activated sludge-sewage mixtures during the initial period of aeration and decreases continually after a more or less constant initial value. The rate of oxygen consumption was 54 p.p.m. in the first hour and 20 p.p.m. per hour after three hours. This initial activity in oxygen consumption is confirmed by Wooldridge and Standfast (20, 21), who used a Barcroft differential manometer and showed that the oxygen absorption by activated sludge-sewage mixtures was greatest during the first hour, as well as in sewage and sludge samples aerated separately. Goldthorpe (22) notes the rate of oxygen absorption by activated sludge sewage mixtures is greatest for the first 30 minutes, and decreases regularly thereafter. McNamee (23) shows that the rate of oxygen absorption by activated sludge mixtures is greatest during the first hour and decreases regularly thereafter up to 6 or 8 hours aeration. Further aeration up to 20 to 24 hours gives uniform absorption results per hour, similar to the absorption rate of the sludge component aerated separately. The oxygen absorption, calculated from the difference between the mixture and the sludge, show similarly decreasing rates with increasing periods of aeration up to 5 to 8 hours. Thereafter the rate of absorption becomes stationary. Ruchhoft, McNamee, and Butterfield (7) later confirm the high rate of oxygen uptake during the initial periods by aerating the special sludge produced from pure cultures of the Butterfield zooglea organism in sterilized natural or synthetic sewage.

From the standpoint of oxygen absorption by activated sludge-sewage mixtures, Heukelekian and Ingols (16) believe this evidence sufficient to indicate that the highest rate occurs during the earliest periods of aeration, whether 10, 20, 30, or 60 minutes and that thereafter for every equal unit of time the rate of oxygen absorption decreases. Such high initial rates of oxygen absorption have not been used previously as supporting evidence of the importance of biochemical oxidation during the clarification stage, because of the possibility that these observed high rates may be due to the chemical reaction of oxygen with some reducing substances. Undoubtedly reducing substances exist in sewage, especially as the sewage becomes stale. However, Wooldridge and Standfast (9) have shown that sterile sewage (autoclaved or Seitz filtered) does not absorb any oxygen. A small part of the initial high rate of oxygen absorption may be attributed to the increase of dissolved oxygen in the mixture during this period. Hence carbon dioxide production must be attributed solely to biochemical oxidation. The respiratory quotients * reported by Wooldridge and Standfast (21) and Heukelekian (24) are lower than normal for the biochemical oxidation of fats, carbohydrates, and proteins, but this condition may be due to high oxygen consumption values or to low CO_2 production values of the activated sludge mixtures. The respiratory quotient increases with the period of aeration, indicating the possibility of a lag period after the oxygen is consumed before CO_2 is produced. It may also increase because of the apparent lower rate of consumption after the dissolved oxygen content of the liquid is built up. Thus both theory and experiment indicate that the oxidative mechanism of activated sludge is ample to account for the initial rapid rate of purification.

Clarification implies the removal of the organic and inorganic matter that causes turbidity. The removal of inorganic matter cannot be attributed to a biochemical reaction. Neither can the oxidative mechanism be held completely responsible for the removal of organic matter. Intervening stages of hydrolysis are essential before the organisms can utilize such matter as a source of energy, followed by a consumption of oxygen and a production of carbon dioxide. The initial high rate of oxidation is attributed chiefly to the soluble materials initially present in sewage. Heukelekian and Ingols (16) believe that activated sludge has an adequate mechanism for hydrolysis, which provides the necessary food for the oxidation mechanism. The processes of clarification and oxidation proceed simultaneously. The highest rate of clarification coincides with the period of highest oxidation rate. The stimulus needed for the different mechanisms is the addition of new food in the form of sewage.

Ruchhoft, McNamee, and Butterfield indicate (25) that a return or unfed sludge may have a demand varying from 10 to 30 milligrams per gram of suspended solids in five hours. Some sludges may have a higher demand. With good activated sludge the fed activated sludge will generally use more oxygen than the control or unfed portion. With non-nitrifying activated sludges fed with substrates having a B.O.D. of 80 to 200 p.p.m., the control sludge requires only about 30 to 50 per cent of the oxygen used by the fed mixture during a 5-hour aeration period.

For practical plant control, Ruchhoft, McNamee, and Butterfield

* The respiratory quotient is the ratio of the volume of carbon dioxide produced to the volume of oxygen used during the same time interval.

(25) suggest observations of oxygen utilization during an aeration period of 1 to 4 hours, with the simplest type of apparatus, such as devised by Bloodgood (26).

Factors in Oxygen Balance.—To study the rate of oxidation in the oxygen balance in an aeration tank, many factors must be known, such as the concentration of the sewage and the purified liquid, the quantity of air, its distribution, the rate of oxygen absorption, the temperature, and the amount of solids in the mixed liquor.

Air an Essential Feature.—Heukelekian points out (27) that the best results in the clarification of sewage by activated sludge were obtained with air, next best by mechanical stirring, and poorest with nitrogen. Agitation with nitrogen gas on some sludges gave a slight initial clarification. With other sludges, clarification did not occur and the supernatent became progressively worse with increasing periods of agitation. This was confirmed by Williams (28) who found that hydrogen or nitrogen were very inferior to air or oxygen. If treatment is continued for more than two hours with hydrogen or nitrogen, some of the organic matter previously flocculated is dispersed, possibly owing to anaerobic conditions.

From a practical standpoint, Haseltine (29) states that the first operating requirement of the activated sludge process is the maintenance of dissolved oxygen in the aeration tanks, and second that the oxygen demand of the mixed liquor should be kept at a minimum. This demand consists of the demands of the return sludge and of the sewage. The demand of the return sludge is the greater. Should the demand of the sludge become excessively low, a starved sludge results, incapable of properly oxidizing the sewage.

Maintenance of Residual Oxygen.—The various methods of control available, whether by an optimum sludge index, ash content of the suspended solids in the mixed liquor, return of sludge with proper absorption qualities, the proper quantity of air per pound of B.O.D. load, chlorination of return sludge, or other chemical means, all have as an ultimate objective the maintenance of dissolved oxygen in a properly aerated mixed liquor (30).

At Chicago, Ill., the dissolved oxygen in the aeration tank is determined every four hours, by collecting a quart sample to which is added 2 cc. of 10 per cent copper sulfate. The bottle is shaken, stoppered, and 250 cc. of the supernatant is siphoned off. On this the oxygen is determined by the sodium azide modification of the Winkler method. By comparison with color standards, the operator approximates the amount of residual dissolved oxygen and can adjust the air supply accordingly. The sample is collected near the surface on the side of the tank opposite to the upflow of air.

If this procedure is followed closely, the operator can reduce the amount of air required to the lowest point necessary for the desired B.O.D. removal. However, attention as to the quantity of sludge returned to the aeration tank is also essential.

Control of Dissolved Oxygen in Aeration Tanks.—At Wards Island, New York City, the operators endeavor to maintain the dissolved oxygen content at 5 p.p.m. in the aeration tanks. At Springfield, Ill., the dissolved oxygen in the effluent of the aeration tanks varies between 4 and 6 p.p.m. At Peoria, Ill., the endeavor is to maintain a minimum of 1 p.p.m. at the one-third point from the inlet, by a test made at 4 hour intervals.

Heukelekian (31) suggests that the minimum dissolved oxygen in the mixed liquor should exceed 0.5 to 1 p.p.m., whereas Collier (32) believes 2 p.p.m. should be a minimum. This latter agrees with the findings at Indianapolis, and the North Side Works, Chicago. At the latter plant the operator attempts to maintain the average daily dissolved oxygen at the outlet of the aeration tanks at approximately 2 p.p.m. by a determination every four hours. On one battery out of three, samples are taken at six points along the length of one aeration tank (410 ft.). In the other two batteries, only one unit tank in each is sampled. At Baltimore, the dissolved oxygen is also determined every four hours.

In many plants, the air used is reduced to an amount sufficient to maintain a low B.O.D. in the effluent with a minimum of nitrates. Some dissolved oxygen should be maintained at the inlet end of the aeration tanks, and the content increased to at least 2 p.p.m. at the outlet. Although some operators report that 0.5 to 1 p.p.m. is satisfactory, it may not prove enough.

Dissolved Oxygen in Final Settling Tanks.—At Lima, Ohio (33), the air is adjusted so that the sewage in the final settling tanks contains 75 per cent saturation of dissolved oxygen, whereas at Elyria, Ohio (34), saturation is maintained at all times, as the plant is underloaded. At Peoria, Ill., Longley reports that the dissolved oxygen in the effluent of the final tanks varies between 2 and 5 p.p.m.

TABLE I.—*The Sanitary District of Chicago, Effluents of North Side and Calumet Works, B.O.D. and Dissolved Oxygen, 1932–1940, Results in Parts per Million*

Year	North Side			Calumet		
	B.O.D. Effluent	Dissolved Oxygen		B.O.D. Effluent	Dissolved Oxygen	
		Final Tk. Effluent	Outfall		Imhoff Effluent	Activated Sludge
1932	9.7	2.4		46.1	1.9	4.4
1933	13.1	2.0		45.7	2.9	4.7
1934	14.1	1.4	8.0	49.3	2.2	5.0
1935	10.1	2.5	9.3	39.4*	3.1*	5.5*
1936	8.5	2.2	9.0	16		7.6
1937	9.2	2.0	8.9	13		7.3
1938	8.6	2.7	9.4	14		7.5
1939	7.7	2.2	8.7	12		7.8
1940	7.0	1.6	8.4	10		8.0

Note.—Prior to December, 1935, the Calumet Works operated largely as an Imhoff tank plant.

* First nine months. Imhoff tank plant shut down thereafter.

The dissolved oxygen in the final effluent is determined twice daily at the North Side Works, Chicago, at 9 A.M. and 3 P.M., but results of this determination are not used by the shift engineers for plant control.

Chicago Experience.—The experience at Chicago in the increase of dissolved and entrained oxygen by the effluent is indicated by Table I. At the North Side Works, the yearly average dissolved oxygen in the final tank effluent varies from 1.4 to 2.7 p.p.m. In dropping into the outfall conduit and in flowing through about 800 ft. to the North Shore Channel, the effluent picks up dissolved and entrained oxygen in an amount which at times approaches saturation in the summer. It is doubtful, however, whether all this air, so rapidly dissolved and entrained, stays in solution and is available for the satisfaction of the

TABLE II.—*Air Required per Unit of 5-Day B.O.D. Removed at Various Activated Sludge Sewage Treatment Works*

Plant	Preliminary Treatment	Length of Record Month or Year	5-Day B.O.D. P. P. M. Primary Effluent	Final Effluent	Removal	Quantity of Air Cu. Ft. per Gal. Sewage	Cu. Ft. per Gal. per P.P.M. B.O.D. Applied	Cu. Ft. per Lb. B.O.D. Removed
Wards Island	1.0 hr. sed.	12	—	17	—	0.70		670
	1.1 hr. sed.	12	168	12	156	0.65	0.00387	500
Chicago								
North Side	None	30	117	11.7	105	0.37	0.00316	423
North Side	20 min. sed.	42	93	8.3	84.7	0.36	0.00387	510
Calumet	15 min. sed.	48	92	14	78	0.38	0.00413	585
Milwaukee	3/32 in. screens							
Old		84	203	10.1	193	1.53	0.00753	951
New		48	171	7.3	164	1.46	0.00852	1070
San Antonio	41 min. sed.							800–1,000
Topeka								1000
Indianapolis	Screens	1938	201	22	179	1.30	0.00647	870
	3/64 in. mesh	1939	231	19	212	1.51	0.00653	855
		1940	240	17	223	1.69	0.00704	911
Springfield, Ill.	60 min. sed.	1937	145	13	132	0.58	0.0040	528
		1938	119	14	105	0.75	0.0063	857
		1939	137	14	123	0.75	0.00548	741
Peoria	2.3 hr. sed.	1939	152	23	129	1.02	0.0067	950
		1940	185	28.6	156	1.00	0.0054	769
North Toronto	2.6 hr. sed.	1940	230	15	215	0.92	0.0043	514
	2.8 hr. sed.	36	208	15.7	192	0.99	0.0049	615
	3.0 hr. sed.	1936	198	14	184	0.96	0.0048	625
	3.28 hr. sed.	1935	178	23	155	0.90	0.0051	697

B.O.D. At the Calumet Works, a somewhat lower increase in dissolved and entrained oxygen is indicated.

Control of Air.—According to Kivell (34) some operators increase the amount of air as the sewage flow increases and becomes stronger, whereas others maintain a constant volume of air per square foot of aeration tank surface, regardless of the volume of flow.

Plant control at Chicago is based chiefly on the routine tests for sludge index and dissolved oxygen in the aeration tanks. Actual experience does not always indicate the need of an increase in air supply during a mild storm. Usually, after a heavy storm, the air can be decreased for several days, owing to the sewage being more diluted.

At San Antonio, Texas, Berg (35) uses more air as the solids in the aeration tanks increase, varying the amount of air to conform to the sludge index. At first Berg endeavored to apply at least 800 cu. ft. of air per lb. of B.O.D. removed by the aeration tanks, but he now considers 1,000 cu. ft. per lb. a minimum for proper operation (Table II).

Measure of Load.—The term "air in cubic feet per gallon of sewage" is not entirely satisfactory as a measure for comparison of aeration tank operation. The term "air in cubic feet per pound of B.O.D. removed by the activated sludge process" has been suggested as more comprehensive. The removal is determined by the difference between the B.D.D. of the influent to the aeration tanks and the B.O.D. of the final settling basin effluent. Data compiled for a number of plants (Table II) show that the amount of air used varies from 423 to 1,070 cu. ft. per pound of B.O.D. removed in the aeration tanks. At Milwaukee, Wis., a comparatively large amount of air is used in the various channels. However, as the air in the channels probably is somewhat beneficial, the larger amount of air is given in the tabulation.

The relation of the removal of B.O.D. in parts per million to the amount of air used in cubic feet per pound of B.O.D. removed is shown in Fig. 1. The line drawn between the points is only tentative.

The points used in Fig. 1 are for the following plants:

Point	Plant	Period Years
1	Wards Island, New York City	1
2	North Side, Chicago	2.5
3	North Side, Chicago	3.5
4	Calumet, Chicago	4
5	Milwaukee, Wis., Old Plant	7
6	Indianapolis, Ind.	3
7	Springfield, Ill.	3
8	Peoria, Ill.	2
9	North Toronto, Ont.	6

Rate of Oxygen Absorption.—Spiegel, Kappe, and Smith (36) state that sludge activity as a measure of the biological activity of activated sludge is proportionate in well-activated sludge to the volatile matter. Oxygen utilized by the biological activity of the sludge may be measured in parts per million per hour. Only the volatile or organic portion of the susspended solids is effective. As solids are added, the activity increase is proportional to the amount of activated solids added and is measured by the rate of oxygen utilization. The rate of oxygen utilization has been studied by using the copper sulfate method of determining the dissolved oxygen (30) on one sample, while another is shaken vigorously for 10 minutes and then treated with copper sulfate. After the floc in both bottles settles for 10 minutes, the dissolved oxygen is determined in the supernatent. The difference is the reduction in dissolved oxygen in 10 minutes. In place of copper sulfate, Watson (37) suggests the use of mercuric chloride. In the United States, copper sulfate is commonly used.

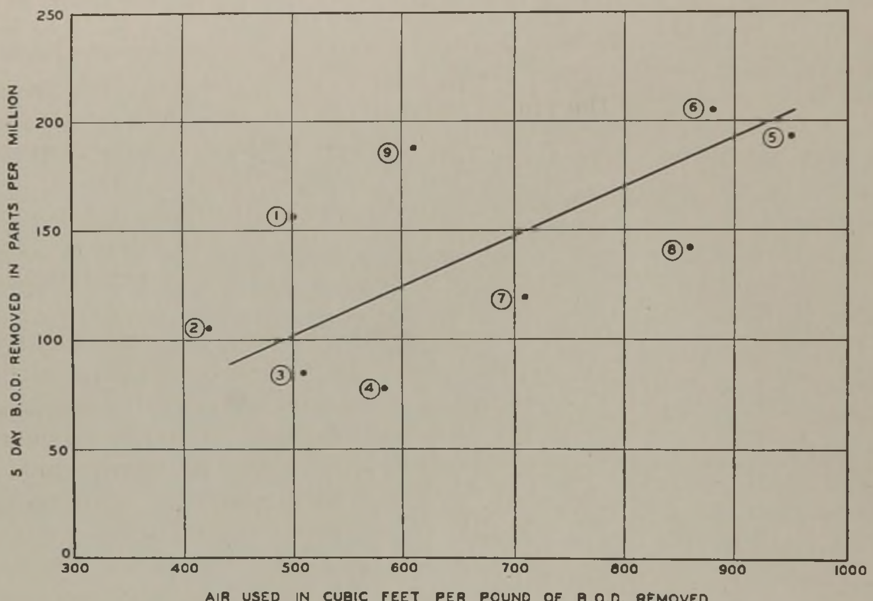


FIG. 1.—Relation between B.O.D. removal and air used.

Among more specific apparatus is the Odeeometer, devised by Nordell to determine the oxygen demand by measuring the shrinkage of air in a closed chamber, caused by the absorption of the oxygen by an activated sludge-sewage mixture contained in the chamber (38). This instrument was tested to a limited extent by Palmer (39) at the North Side Works, Chicago, but was not adopted. At Elyria, Ohio, Collier (41) reports that it is of value. Hicks and Box (40) note certain fundamental difficulties in the application of the Odeeometer, as does Bloodgood at Indianapolis. Enslow (42) points out that the treatment plant itself is its own best Odeeometer, since the amount of dissolved oxygen in the aeration and final settling tanks is a good indicator of operating conditions.

The rates of air solution and of utilization for sewage treatment by the activated sludge process are discussed by Hicks and Box (40), following the papers of Kessener and Ribbius (43), Watson (37), and Goldthorpe (22) upon the premise that the most important single factor is the supply of oxygen to the sludge and the liquor. This view is also held by Adeney (44). Two factors need determination: first, the rate at which oxygen from solution can be utilized biochemically by the sewage sludge mixture, and second, by the rate at which oxygen can be introduced chemically into such a mixture.

Hicks and Box (40) roughly classify the methods of determining the oxygen demand into those based on the assumption that the oxygen demand of activated sludge is independent of the dissolved oxygen concentration in the liquid with which the sludge is in contact, and those in which is noted the reduction in the volume of air in contact with the sludge and the liquor when these are mixed in a closed aerating system. In evaluating the demand when based on the first assumption by determinations of the dissolved oxygen in a sample at various short time intervals, certain complications occur, which Hicks and Box feel are removed by centrifuging the sludge mixture before determining the dissolved oxygen. When based on the second assumption, such apparatus as the Odeeometer is used, in which air is supplied to the mixture by a paddle, and those in which air is actually drawn through or forced in bubbles through the contained liquid (Theriault (45); Goldthorpe (22); Bloodgood (26); Sawyer and Nichols (46)). Devices for removing the CO_2 produced may be incorporated.

Hicks and Box (40) indicate that the dissolved oxygen concentration in a sample of sludge taken from a plant is probably changing during the initial aeration period in any oxygen demand meter of the mechanical type; hence such meters give misleading rates of oxygen demand until the dissolved oxygen concentration has reached an equilibrium.

Ruchhoft (47) indicates that the biochemical condition of a sludge may be determined by the quantity of oxygen required by the mixed liquor or sludge alone as it is returned to the effluent end of the aeration tank and that poor activated sludge does not possess a greatly increased demand for oxygen during the first 3 or 4 hours when dosed with sewage, whereas good activated sludge does. He suggests comparing the biochemical oxidation activity of a sludge in an undosed and a sewage dose mixture as a measure of the condition of the sludge.

Indianapolis Method.—A procedure and device have been developed by Bloodgood at Indianapolis (26, 48) to determine two factors:

1. The sludge demand, namely, the amount of oxygen in p.p.m. per hour used by a 0.50 per cent solids sludge which has had its normal period of aeration with sewage. This demand is a measure of the unoxidized matter in the sludge.
2. The sludge activity, which is the rate of oxygen consumption, less the sludge demand, when synthetic sewage and sludge are combined to form a 0.50 per cent mixture of suspended solids. This activity, expressed in p.p.m. per hour, indicates the rate at which sludge can be expected to purify sewage and its settling characteristics.

The sample of sludge is taken from the effluent end of an aeration tank. To keep the Indianapolis plant in good condition, the sludge demand is kept between 25 and 50 p.p.m. per hour. A gradual increase from day to day indicates overloading. A slight increase may be reduced over the weekend. The maximum sludge activity is kept between 70 and 100 p.p.m. If the activity goes higher, the sludge does not concentrate well.

The sludge demand and the sludge activity can be controlled by varying the quantity of air used or the quantity of mixed liquor solids, or by varying the detention period in the aeration tanks, if conditions permit. The Indianapolis procedure has also been used at the activated sludge plants at Richmond, Ind.; Ann Arbor, Mich.; Baltimore, Md.; and Wards Island, New York City.

Period of Aeration

At Monroe, Wis. (50), the maximum rate of oxygen utilization occurred during a short period after the initial mixing of the raw sewage and the activated sludge, followed by a sharp drop, and a steadily declining rate thereafter. At other sewage works, in any given activated sludge-sewage mixture, with a constant maximum sludge activity, the time of aeration required has been noted to be directly proportional to the sewage strength, and in any given activated sludge-sewage mixture where the sewage strength remains the same, the aeration period required to produce a well-conditioned sludge varies inversely with the maximum sludge activity.

The procedure for the control of an activated sludge plant involves the maintenance of a sludge activity which will produce a well activated sludge within the aeration period available. The desired maximum sludge activity can be maintained by controlling the wastage and the re-

Table III.—*Period of Aeration in Hours at Various Activated Sludge Sewage Treatment Works, 1930–1940*

Year	Chicago, S. D.		Milwaukee, Wis.				Springfield, Ill.	Indianapolis, Ind.	Cleveland (Easterly), Ohio	North Toronto, Ont.	Wards Island, N. Y.	Peoria, Ill.	San Antonio	
	North Side	Calumet	West Aeration Tank	(Old) Total	East Aeration Tank	(New) Total							Aeration	Reaeration
1930	5.3						5.3	8.26						
1931	5.2						4.8	8.40				10.1[a]		
1932	4.9						5.0	8.89				9.6	7.55	1.01
1933	5.2		5.81	6.71			5.3					10.3	7.72	1.03
1934	5.4		5.56	6.36			5.6	8.76				11.3	7.68	1.03
1935	4.5		5.57	6.19			5.3	8.28		6.9		9.5	6.58	0.97
1936	4.3	4.7	5.73	6.43	11.50	13.52	6.1	9.25		7.14		6.3	6.78	0.95
1937	4.2	5.3	5.52	6.74	9.74	12.37	6.4	10.46		6.71		6.5	7.56	1.12
1938	5.1	5.2	6.28	7.05	9.33	11.85	6.6	8.33	8.1	7.16	5.6[b]	6.2	7.78	1.29
1939	4.7	4.2	6.08	6.79	9.08	11.57	6.7	8.75	7.6	6.64	5.3	5.8	7.56	1.24
1940	5.5	4.6	6.27	7.01	9.56	10.71	7.0	9.10	6.9	6.4	4.6	5.2	7.03	1.08

[a] 5 months period. [b] 9 months period.

tention of sludge. However, the sludge index and the settling characteristics of the sludge must also be determined. Heukelekian (31) believes the B.O.D. of activated sludge may prove a good index to determine its degree of oxidation. However, this B.O.D. is affected not only by the stage of oxidation, but also by the concentration of the sludge. Therefore, results should be expressed on the basis of the amount of suspended solids. The difficulty is to find a satisfactory test that takes less time than a 5-day demand test. The B.O.D. as determined on the basis of a unit amount of suspended solids decreases as the amount of activated sludge in a mixture increases in relation to sewage, and it further decreases in a given mixture as the aeration period increases.

The actual aeration periods in various plants (Table III) have ranged from 4 to 13.5 hours. At Chicago, around 5 hours is considered sufficient, whereas at Milwaukee 6 hours is now used in the old plant. At Springfield, Ill., from 6.1 to 7 hours is reported, whereas at Indianapolis from 8.3 to 10.5 hours is shown. The period of aeration depends on the degree of purification sought and the amount of nitrification.

Short Circuiting.—Apparently short circuiting in aeration tanks is not very common in the United States, because aeration channels are relatively long in proportion to the widths. At Hagerstown, Md., cross baffles with a relatively small opening in the lower corner near the diffusers were installed. However, short circuiting may be more common than appears from published reports, because few plants have been examined to see if short circuiting exists. The nature of short circuiting has been discussed by Kehr (120) who found that detention in relatively short activated sludge aeration tanks in a testing station approximated that obtained by assuming instantaneous and complete mixing of the tank contents. (See paper by Fair and McKee, this issue, p. .)

Short Period Aeration.—At the North Side Works, Chicago, for a period of three years, one battery of aeration tanks operated with a detention period of from 3.0 to 3.3 hours, as compared with a 4.5 to 5 hour period in the other two batteries. The results are roughly summarized as follows:

Data	1935 Battery		1936 Battery		1937 Battery	
	B	A and C	B	A and C	B	A and C
Aeration Period, Hr.	3.3	5.1	3.0	5.0	3.0	4.5
Air, Cu. ft. per Gal.	0.37	0.36	0.37	0.36	0.35	0.35
Sludge Index	62	65	66	68	78	81
Effluent						
B.O.D., P.P.M.	10.7	9.6	9.7	8.0	9.5	9.1
Susp. Solids, P.P.M.	14	13	15.0	14.0	13.0	12.0

In 1937, an experimental activated sludge unit was installed at the West Side Works, which operated on Imhoff tank effluent for about twelve months, with aeration periods of 1.25, 1.5, and 2.1 hours. The results were as follows:

Data	Aeration Period in Hours		
	1.25	1.45	2.1
Air, Cu. Ft. per Gal.	0.24	0.18	0.25
Return Sludge, Per Ct.	27.5	15.6	11.5
Mixed Liquor, P.P.M.	1,960	2,370	2,260
Sludge Index	268	80	58
Raw Sewage			
B.O.D., P.P.M.	84	89	101
Suspended Solids, P.P.M.	117	118	119
Imhoff Effluent			
B.O.D., P.P.M.	38	42	70
Suspended Solids, P.P.M.	42	47	67
Final Effluent			
B.O.D., P.P.M.	11.5	9.4	12.5
Suspended Solids, P.P.M.	9	12	19
Settling Rate			
Gal. per Sq. Ft. per Day	1,858	1,620	1,114

The settling rates in the final sedimentation were limited by the apparatus available.

These results indicate that even with such extreme conditions, considerable purification was effected with relatively short periods of aeration. On the weak settled Imhoff tank effluent handled at the West Side, 1.5 hours appears to be a critical point. However, such short periods appear to lack flexibility, particularly where a high grade effluent is required.

Relation Between B.O.D. Removal and Aeration Period.—The relation between the B.O.D. removal and the aeration period at several activated sludge plants is shown in Fig. 2. The plat shows a trend towards a longer aeration period for accomplishing greater removal of B.O.D.

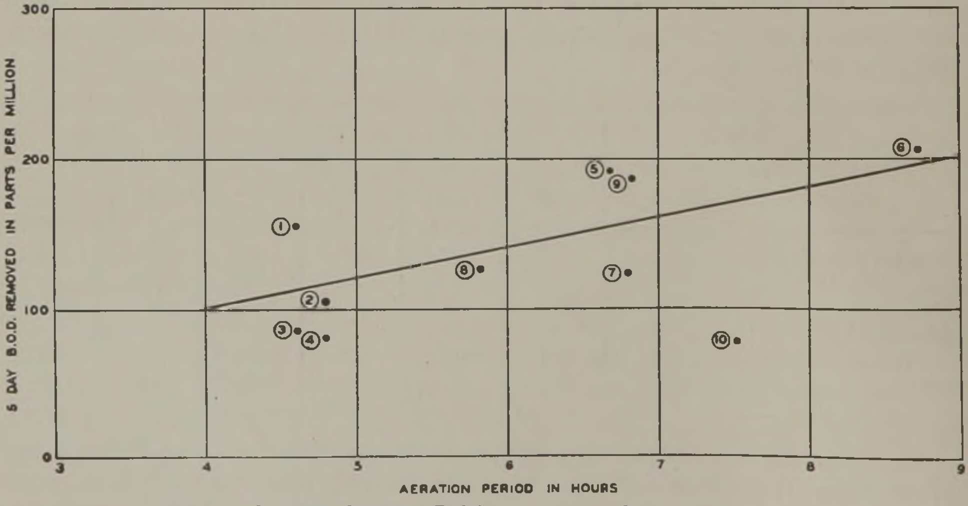


FIG. 2.—Relation between B.O.D. removal and aeration period.

Reference Fig. 2.—The points used in Fig. 2 are for the following plants:

Point	Plant	Period Years
1	Wards Island, New York City	1
2	North Side, Chicago	2.5
3	North Side, Chicago	3.5
4	Calumet, Chicago	4
5	Milwaukee, Wis., Old Plant	7
6	Indianapolis, Ind.	3
7	Springfield, Ill.	4
8	Peoria, Ill.	2
9	North Toronto, Ont.	6
10	Cleveland, Ohio	3

Nitrification.—In the early days of the activated sludge process, the objective was an effluent well-nitrified and clarified. Nitrate nitrogen was reported as high as 6.9 p.p.m. at the Des Plaines River Works, Chicago, and 8.7 p.p.m. at the Milwaukee Testing Station. Houston (51) reported a yearly average of 11.3 p.p.m. in 1923 at its South Side plant and 4.1 p.p.m. at its North Side plant. As studies progressed on biochemical oxidation and the satisfaction of B.O.D., it became evident that the use of non-nitrifying sludges gave a more economical plant to operate, because of the shorter aeration period required, as well as the lower amount of air. In recent years the Easterly plant at Cleveland, Ohio shows in 1939 an average of 10 p.p.m. of nitrate nitrogen, with a maximum month of 12.4 p.p.m. and a maximum day of 20 p.p.m. The Cleveland plant was then operated at an average rate of 80.6 m.g.d. as compared with a design capacity of 123 m.g.d. In 1940, however, the nitrate nitrogen averaged 3.7 p.p.m. with a maximum day of 20 p.p.m. and a maximum month of 7.4 p.p.m. The nitrate found in the effluents of various activated sludge plants is shown in Table IV for the period 1930–1940, inclusive.

Tapered Aeration.—Haseltine (29) used tapered aeration at the Salinas, Cal., plant from 1930 to 1933, applying 55 to 70 per cent of the total air in the first half of the aeration tanks. At Chicago, Indianapolis, and Milwaukee, no attempt is made to taper the aeration.

Laboratory experiments by Ruchhoft, McNamee, and Butterfield (25) indicate the amount of air tapering permissible from the standpoint of biochemical oxidation depends on the oxygen requirement of the sludge itself. Experimental values indicate from 40 to 50 per cent of the air is required in the first 2 hours; 28 to 31 per cent in the second 2 hours; and 20 to 29 per cent in the third 2 hours, for a 6-hour period, using non-nitrifying sludge. Haseltine (29) confirms this at Salinas, where from 55 to 70 per cent of the total air was used in the first half of the aeration tanks. The air required increased with high flows or bulked sludge. At the North Side, Chicago, the relation of the intial

TABLE IV.—*Nitrates in Effluents from Various Activated Sludge Sewage Treatment Works, 1930–1940, Results in Parts Per Million*

Year	Chicago S. D.		Milwaukee, Wis.		Spring-field, Ill.	San Antonio, Texas	Indi-anapolis, Ind.	Cleve-land, Ohio	North Toronto, Ont.	Wards Island, N. Y.	Peoria, Ill.
	North Side	Calumet	West (Old)	East (New)							
1930	2.0				7.2		0.49				
1931	2.2				6.4		0.34				6.1[b]
1932	3.3				5.4	5.3					5.7
1933	2.7		2.37		5.5	6.9					6.7
1934	2.3		2.91		5.4	5.0					5.1
1935	1.6		2.70		7.9	4.5			2.1		5.1
1936	1.0	1.3	4.9		4.7	1.7	8.56		6.9		3.4
1937	0.6	1.0	4.5	4.5	4.2	1.2	7.69		8.8		3.6
1938	1.1	1.2	3.03	2.10	4.5	1.4	2.15	2.9	6.9		2.0
1939	0.7	1.9	4.45	3.01	3.4	0.8	3.46	10.0	7.4	0.5[a]	1.8
1940	0.6	1.1	5.4	3.7	2.2	3.2		3.6	6.4	0.57	2.3

[a] 10 months period. [b] 5 months period.

oxygen demand to the final is about 2 to 1, whereas at Milwaukee, the relation is about 4 to 1.

Variation of Dissolved Oxygen in Aeration Tanks.—Ridenour and Henderson (52) note a variation in the dissolved oxygen in the mixed liquor at various depths in the aeration tank as well as longitudinally along the tank.

Seasonal Aeration.—At some sewage works the practice is to use the activated sludge process only during the warmer months of the year, when a highly purified effluent is required. Such seasonal aeration is practiced by Rhodes at Hagerstown, Md., Collier at Elyria, Ohio, and Smith at Lima, Ohio (53). In 1933, at Lima, O'Brien (54) notes that the plant was out of service from January to April, with a saving of $3,500 on the cost of power. No difficulty is experienced in starting up after the shutdown, and normal operation was possible after two weeks' operation. In fact, a good degree of treatment was reached in a week.

At Indianapolis, part of the works is operated as an aeration plant, without sludge return. This procedure was adopted because it was found that even though the removal of B.O.D. was lower for the aeration only, a much greater volume of sewage could be treated by the plant as a whole, with a greater total removal of B.O.D. than if the entire plant were on an activated sludge basis. For the past four years, 1937 to 1940 inclusive, from 40 to 60 per cent of the flow has received aeration only, with a B.O.D. removal around 62 per cent. Some oxidation is accomplished, and the sewage is flocculated sufficiently to obtain good settling in the final tanks. Results from 1935 through 1940 (55) are shown in Table V. The percentages given indicate the overall efficiency of the entire plant, including fine screens and preliminary settling tanks as well as the aeration tanks and final settling tanks.

In Ohio (32) Collier reports B.O.D. removal of 65 to 70 per cent with plain aeration, using around 0.5 cu. ft. of air per gallon of sewage. A

Table V.—*Comparison of Plain Aeration and Activated Sludge, Indianapolis, Ind.*

Year	Activated Sludge					Aeration Only				
	Flow Treated, M.G.D.	Removal Susp. Solids, Per Ct.	Removal B.O.D., Per Ct.	Air, Cu Ft. per Gal.	Aeration Period Hr.	Flow Treated, M.G.D.	Removal Susp. Solids, Per Ct.	Removal B.O.D., Per Ct.	Air, Cu. Ft. per Gal.	Aeration Period, Hr.
1935	2.2	93.1	88.5	1.23	8.28	39.9	82.5	60.6	0.49	6.92
1936	3.6	96.2	93.4	1.51	9.25	38.4	81.5	62.0	0.56	7.24
1937	25.3	95.6	92.1	1.25	10.46	23.5	—	58.6	0.41	9.94
1938	30	96.5	90.2	1.30	8.33	22.6	—	63.5	0.53	7.83
1939	21.1	97.8	92.8	1.51	8.75	30.2	—	66.9	0.41	6.72
1940	19.3	98.3	93.9	1.69	9.10	31.6	—	63.0	0.47	8.24

smaller volume of sludge was produced than with the activated sludge process.

Such modifications in the operation of an activated sludge plant may be considered where local stream conditions may permit a lower degree of treatment during certain seasons.

Production of Carbon Dioxide.—From the standpoint of research rather than control, Heukelekian (31) indicates that the amount of CO_2 produced by a sludge during aeration may be a measure of its stage of oxidation. Heukelekian and Ingols (16) suggest the possible use of a method to determine the CO_2 production from activated sludge mixtures for measuring the load on an aeration tank.

Jenkins and Roberts (57) at Birmingham, England, found the proportion of organic carbon oxidized to carbon dioxide is variable. In a 24-hour aeration period, the solids removed early had a higher ratio of carbon to nitrogen than for the later removals. About 20 per cent of the organic carbon quickly flocculated is oxidized to carbon dioxide, whereas the solid removed later is more fully oxidized. Wilson and Clausen (58) report only about 10 per cent of the transformation products of carbon appear as carbon dioxide. They do not regard carbon dioxide as a major product of aerobic oxidation.

Operating Variables

In the operation of an activated sludge plant, Palmer (39) has indicated a number of variables which influence the control:

Concentration of solids in mixed liquor.
Quantity of air used.
Aeration period.
Settling period.
Rate of sludge return.
Sludge condition as indicated by a determination of the oxygen consumption (suggested by Bender).

Activated Sludge Characteristics.—The characteristics of activated sludge have been discussed from various viewpoints by many observers.

Buswell discusses the biological phases in an historical review (56). Other observers have commented on the effect of *Sphaerotilus* (see Bulking), which in excessive quantities change a normally flocculent sludge into stringy material which may accompany bulking. The number of protozoa in the activated sludge is of interest. Heukelekian (31) concludes that the higher the concentration of activated sludge the lower the number of small organisms and the higher the number of large organisms. He also believes the number of bacteria in sludge is not important, if the relation between the sewage load and the sludge is properly maintained. Then the bacterial numbers on the basis of solids will be at a low level and a higher degree of purification will be obtained. As the numbers of bacteria on the dry basis increase, the greater is the amount of activated sludge in relation to the sewage.

Activated sludge in good condition is usually (31) golden brown in color, but if septic or under-aerated it becomes black. A greyish color may indicate an excessive amount of unoxidized raw solids caused by under-aeration or overloading.

Good activated sludge (31) has a pleasant musty, earthy odor when in circulation in the aeration tanks. When settled out, it may turn black in a few hours and become septic if deprived of air for some length of time.

Ash.—Although the ash content of activated sludge should increase as the solids are oxidized, this test as yet has not been used for routine control of the activated sludge process (32, 59, 60). The yearly averages of the volatile content of suspended solids in the raw sewage and return sludge are shown in Table VI for the three major plants at Chicago.

TABLE VI.—*Volatile Matter as Per Cent of Suspended Solids in Raw Sewage and Return Activated Sludge, The Sanitary District of Chicago, Yearly Averages*

	North Side, Per Cent Volatile		Calumet, Per Cent Volatile		Southwest, Per Cent Volatile	
	Raw	Return	Raw	Return	Raw	Return
1930	70.0	64.3				
1	71.5	63.8				
2	68.1	65.6				
3	71.3	70.6				
4	71.2	71.0				
5	67.3	67.8				
6	67.1	68.1	58.7	52.0		
7	66.4	68.8	59.6	52.8		
8	64.2	67.8	59.9	55.6		
9	67.3	69.9	61.0	57.0	71.2[a]	70.3
1940	67.1	71.2	63.0	61.0	70.4	71.2

[a] 6 months.

At the North Side Works, at first the volatile matter in the raw sewage solids was higher, but later on it was lower than the volatile matter in the return sludge. At the Calumet Works, the volatile matter in the return sludge has been consistently lower than in the raw sewage.

The ash content of the sewage from combined systems of sewers varies considerably because of storm flows. This variation is generally much less in the sewage from separate than combined systems. Table VII shows the variations in monthly averages in the volatile matter at

TABLE VII.—*The Sanitary District of Chicago, Volatile Matter as Per Cent of Suspended Solids in Raw Sewage at Major Sewage Works, Monthly Averages*

Year	North Side			Calumet			Southwest			West Side		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
1930	70.0	79.6	64.5							72.3[b]	72.5	72.0
1931	71.5	80.5	65.5							65.6	79.0	60.7
1932	68.1	73.1	61.8							66.2	72.2	60.2
1933	71.3	76.5	62.3							65.7	73.0	58.5
1934	71.2	77.8	62.6							64.1	70.7	57.6
1935	67.3	74.0	61.2							63.8	70.0	54.8
1936	67.1	72.7	59.2	58.7	62.7	54.1				66.0	71.0	60.2
1937	66.4	72.0	60.9	59.6	65.9	53.7				69.1	77.0	60.6
1938	64.2	69.3	56.6	59.9	65.9	55.7				70.3	76.5	63.2
1939	67.3	75.0	60.2	61.0	67.4	54.1	71.2[a]	78.2	65.6	66.9	72.7	55.7
1940	67.1	71.1	61.1	63.0	67.5	59.0	70.4	73.5	63.8	70.5[c]	73.0	65.4

[a] Last 6 months only. [b] Last 3 months only. [c] Computed.

the four major plants at Chicago. In the operation of plants serving large areas such as the North Side Works in Chicago, the ash decreases during prolonged dry periods, with a consequent tendency for the production of a lighter sludge. To increase the ash at Bernardsville, N. J., Gavett (62) added clay to aid settling when the sludge was light. On the other hand, Edwards (61) did not find the use of clay or soil satisfactory at Wards Island.

Edwards also notes (61) a variation in the volatile content of the sludge as follows:

Plant	Per Cent Volatile		
	Average	Maximum	Minimum
Wards Island	76	85	65
Tallmans Island	58.5	77	38

Concentration of Suspended Solids in Aeration Tanks.—In studying the effect of additions of sewage solids in various proportion to the mixed liquor ranging from 3.4 to 17.7 per cent, Heukelekian (63) found that 3.4 per cent was too low to give good results, producing a high ash content in the sludge, a low ratio of B.O.D. to suspended solids, and a turbid effluent; and that 17.7 per cent was excessive, forming a low ash content in the sludge, a high B.O.D., suspended solids ratio, and an effluent high in suspended solids. Ruchhoft, McNamee, and Butterfield (25) conclude, from experiments, that "there is no single optimum quantity of activated sludge to be carried by all plants, but that each plant will require a different optimum quantity of sludge, dependent upon the character and strength of the sewage and the cycle of operations. In general, no more sludge than is necessary to maintain a satisfactory plant effluent should be carried for the most economical operation."

The control of the mixed liquor is thus very important in the operation of activated sludge plants. The concentration of suspended solids in the mixed liquor in aeration tanks at various plants is shown in Table VIII for a term of years. There has been a general trend toward lower concentrations.

TABLE VIII.—*Suspended Solids in Mixed Liquor at Various Activated Sludge Sewage Treatment Works, 1930–1940. Results in Parts Per Million*

Year	Chicago S. D.		Milwaukee, Wis.		Springfield, Ill.	San Antonio, Texas	Indianapolis, Ind.	Cleveland, Ohio	North Toronto, Ont.	Wards Island, N. Y.	Peoria, Ill.
	North Side	Calumet	West (Old)	East (New)							
1930	3,800				4,181		2,100				
1931	3,200				3,433		1,600				2,790[a]
1932	2,800				3,013	2,700	1,300				2,620
1933	2,200		2,966		2,188	2,800					1,550
1934	2,400		3,158		2,400	2,600	1,800				1,020
1935	2,300		3,333		1,583	2,000	1,600		3,190		1,790
1936	2,400	2,700	3,791	3,658	1,390	1,700	2,500		2,740		1,400
1937	2,300	2,690	3,967	4,075	1,886	1,600	2,600		2,340		1,450
1938	2,300	2,230	3,833	3,917	1,362	1,400	2,900		2.410	1,520	1,510
1939	2,400	3,630	3,533	3,633	1,588	1,600	2,900	2,660	2,670	1,540	1,710
1940	2,400	3,830	3,558	3,558	1,840	1,500	2,000	2,804	2,910	1,900	1,820

[a] Five months period.

At the North Side Works, Chicago, the original practice was to maintain about 4,000 p.p.m. of suspended solids in the mixed liquor. For test purposes, the solids were lowered to 1,200 p.p.m. The present practice is to average around 2,300 p.p.m., although following storms the solids may increase to over 3,500 p.p.m. Milwaukee, Wis., has consistently endeavored to keep around 3,500 p.p.m. in the mixed liquor. At Peoria, Ill., better results were reported with 1,800 to 2,000 p.p.m. than with 3,500 (34). At Springfield, Ill., better results were reported in 1935 (34) with 1,800 to 2,000 p.p.m. than with 3,500 carried in 1930 and 1931. Since then Larson reports that the minimum should not go below 1,000 p.p.m. under Springfield conditions. He advises carrying a lower solid content in the summer and a higher in the winter. Collier (33) reports that at Lima, Ohio, the mixed liquor contains 5,000 p.p.m.

After settling for 30 minutes the sludge amounts to about 20 per cent of the volume of the mixed liquor.

Ridenour (64) reports the use of less than 500 p.p.m. of suspended solids in the mixed liquor with an average domestic sewage when using mechanical aeration. In general mechanical aeration plants maintain a lower concentration of suspended solids in the mixed liquor than air-diffusion plants.

Sawyer (65) indicates that the use of low concentrations of suspended solids in aeration tanks produces sludges with high volatile solids content and high activity as measured by the base rates of oxygen utilization. Because of the high activity the solids must be removed rapidly from the final settling tanks and kept in contact with dissolved oxygen to maintain them in proper condition. A high concentration of solids produces sludge with lower volatile solids and lower base rates of oxygen utilization. The solids become more compact and may be

TABLE IX.—*Ratio of Return Solids to Incoming Solids in Aeration Tanks at Various Activated Sludge Sewage Treatment Works*

Plant	Year	Solids in P.P.M.		Return Flow, Per Cent	Ratio Return to Applied $x:1$
		Applied	Return		
Chicago					
North Side	1936	118[a]	11,300	21.6	20.7
	1937	102[a]	10,400	22.5	23.0
	1938	108[a]	10,700	22.4	22.2
	1939	111[a]	10,400	22.9	21.5
	1940	131	11,600	22.4	19.8
Calumet	1936	176	15,200	21.8	18.2
	1937	151	14,800	22.5	22.0
	1938	133	13,400	24.7	24.9
	1939	127	16,100	27.8	35.2
	1940	121	16,100	29.7	39.6
Indianapolis	1936	215	6,400	53	15.8
	1937	215	10,400	27	13.1
	1938	224	10,800	32	15.4
	1939	265	8,900	44	14.8
	1940	252	7,900	40	12.5
Milwaukee	1936	261	16,700	31.3	20.0
Old	1937	278	16,600	32.3	19.3
	1938	256	19,000	26.4	19.6
	1939	268	15,100	31.8	17.9
	1940	290	16,600	27.2	15.5
New	1936	261	16,700	22.6	14.5
	1937	278	16,600	29.3	17.5
	1938	256	19,000	23.6	18.2
	1939	268	15,100	25.6	14.4
	1940	290	16,100	22.4	12.4

[a] Estimated from raw sewage, reduced by preliminary sludge.

TABLE IX.—*Continued*

Plant	Year	Solids in P.P.M.		Return Flow, Per Cent	Ratio Return to Applied $x:1$
		Applied	Return		
Springfield	1936	103	5,838	23	13.1
	1937	161	8,684	20	10.8
	1938	94	4,866	28	14.5
	1939	129	6,475	29	14.5
	1940	123	6,730	30	16.4
Peoria	1937	138	5,200	35.2	13.2
	1938	137	4,220	35.3	10.9
	1939	125	7,700	23.9	14.7
	1940	128		40.7	18.5
Cleveland	1939	115	15,260	21.9	29.0
	1940	135	13,750	25.0	25.4
Wards Island	1939			37	13.4
	1940	161	4,925	45	14.3
San Antonio					10
North Toronto	1935	126	14,400	31	35
	1936	149	14,900	23	23
	1937	162	13,400	21	17
	1938	160	15,200	19	18
	1939	172	15,200	23	20
	1940	160	13,360	30	25

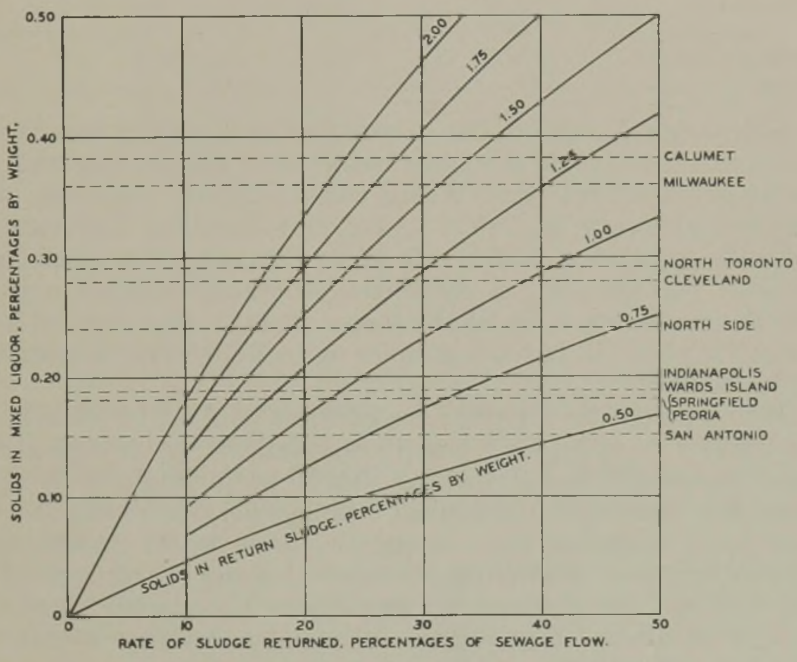
kept for longer periods without aeration than sludge with high volatile solids.

When low concentrations of suspended solids are carried in the aeration tanks, the rate of sludge build-up is greater; when larger amounts of suspended solids are carried, the rate of sludge build-up is less. From the standpoint of fertilizer production, operation with low suspended solids yields higher amounts of product. From the standpoint of sludge disposal, carrying high suspended solids yields lower quantities of dry solids to be handled as sludge (65). However, when lower solids concentrations are carried, a thinner or more voluminous sludge is produced. When the sludge index is around 100, a mixed liquor content of solids can be maintained around 2,000 p.p.m. A low index around 50 permits carrying around 3,000 to 4,000 p.p.m. (67) (Tables IX and X, Fig. 3).

The relation between the solids in the return sludge and in the mixed liquor to the rate of sludge returned is shown in Fig. 3. This diagram is patterned after the diagram of Regester (4), but the 1940 practice of various municipalities on the mixed liquor solids is superimposed, instead of the 1937 practice as shown by him. The effect of the solids in the sewage is neglected. In studying this diagram, the following relations can be assumed:

Solids in Return Sludge, Per Cent	Sludge Index
0.50	200
0.75	133
1.00	100
1.25	80
1.50	67
1.75	57
2.00	50

Ratio of Returned Solids to Incoming Solids.—Table IX summarizes the relation of returned solids to the sewage solids entering the aeration tanks (after preliminary treatment, if any) at a number of plants. The results vary from a low ratio of 10:1 at San Antonio (35) to 39.6:1 at the Calumet plant, Chicago, for one year. Out of eleven plants the



NOTE: 1940 PRACTICE OF MAINTAINING SOLIDS IN AERATED MIXTURES IS SUPERIMPOSED

FIG. 3.—Relation of solids in return sludge and in mixed liquor to the rate of sludge returned.

range for seven falls within 10:1 and 20:1. In analyzing such figures the relation of volatile solids might also be considered, inasmuch as the per cent of volatile varies considerably among the plants listed. North Toronto, Ont., and Wards Island, New York City, have probably the highest volatile content, and the Calumet works the lowest (Table X). There is a general trend towards higher return solids where the volatile solids are lower, although North Toronto is a marked exception.

TABLE X.—*Comparison of Volatile Content of Suspended Matter in Raw Sewage and Ratio of Return Solids to Applied Solids*

Plant	Length of Record, Years	Suspended Solids		Ratio of Return Solids to Applied $x:1$
		Volatile, Per Cent	Ash, Per Cent	
North Toronto	5	82.4	17.6	23
Wards Island	2.25	81.3	18.7	13.9
Peoria	9.4	76.3	23.7	14.3
Milwaukee	4	75.1	24.9	
New				15.4
Old				18.5
Cleveland				
Easterly	1	67.5	32.5	25.4
Springfield	10	65.0	35.0	13.9
Chicago				
North Side	11	68.1	31.9	21.4
Calumet	5	64.3	35.7	28.0
Southwest	1.5	70.7	29.3	
Tallmans Island	0.75	58.5	41.5	

Sampling.—To determine accurately the operating results as many samples as practicable should be collected at regular intervals through the 24 hours of the day. Where composites are required, automatic samplers are very desirable. As a rule sampling intervals are not varied in proportion to the rate of flow unless some special data are desired. Nor are samples collected hourly and weighted in accordance with the respective flows at the larger plants. However, at a number of smaller plants in Indiana samples are collected and weighted according to the flow.

Where automatic samplers are used, care should be taken in locating the sampler to avoid long pipe lines, particularly on high-grade effluents. Relatively high velocities should be maintained in the pipes. Even then manual or mechanical cleaning may be required. In some cases hand sampling may be preferable to avoid contamination by growths in pipes. Sampling is discussed along broad lines by a Committee of the New England Sewage Works Association (29a).

Routine Tests.—The routine laboratory analyses useful in plant operation are as follows (30):

Raw Sewage and Settled Effluent—
Biochemical oxygen demand, suspended solids, volatile suspended solids, organic nitrogen, ammonia nitrogen, settleable solids, pH.

Activated Sludge Effluent—
Biochemical oxygen demand, suspended solids, volatile suspended solids, organic nitrogen, ammonia nitrogen, nitrate and nitrite nitrogen, dissolved oxygen.

Activated Sludge Aeration Tank—
Suspended solids, settleable solids, dissolved oxygen.

Return Activated Sludge—
Total suspended solids.
Primary or Wasted Sludge—
Total suspended solids, volatile solids, pH.

Some operators still report total solids in the raw sewage and effluents (Table XI), as at Cleveland, Indianapolis, and San Antonio. Usually this practice is followed because of special conditions. Under normal conditions the determination of the total mineral and volatile suspended matter is sufficient and more informative. Monthly averages are shown for the year 1940 at Cleveland (Table XII). At San Antonio the suspended solids are the smallest proportion of the total solids for the three cities cited.

TABLE XI.—*Total Solids and Suspended Solids in Raw Sewage, Cleveland, Indianapolis, and San Antonio, Monthly Averages, Results in Parts Per Million*

	Total Solids			Suspended Solids		
	Avg.	Max.	Min.	Avg.	Max	Min.
Cleveland						
Easterly Works						
1939	674	720	641	241	272	218
1940	681	723	634	238	266	218
Indianapolis						
1935	1,024	1,133	897	365	399	317
1936	1,045	1,167	947	346	456	279
1937	969	1,064	910	323	362	280
1938	1,028	1,211	909	312	416	251
1939	1,046	1,218	951	371	485	273
1940	1,036	1,187	961	403	468	304
San Antonio						
1935	1,024	1,205	786	261	313	208
1940	930	1,080	837	279	346	238

Microscopic Control.—The use of the microscope is generally conceded to be a valuable aid to plant control, particularly where bulking is liable to occur. However, practice varies. At Lima, Ohio (33), and at Wards Island, New York City, a daily microscopical examination is made of the mixed liquor. At Wards Island the sewage has a high content of volatile solids. At Springfield, Larson only makes an examination about once a week unless the aeration tanks are not functioning properly. At Peoria, Kraus makes an occasional microscopic examination, but does not use it as a control as filamentous bacteria are practically always present. At Chicago, routine microscopical examinations are not made, because bulking occurs infrequently. Studies at the North Side for a year in 1932–33 indicated no particular value in routine microscopical examinations.

Table XII.—*Total Solids and Suspended Solids in Raw Sewage, Cleveland Easterly Works, 1940*

1940	Total Solids			Suspended Solids		
	Total, P.P.M.	Fixed, P.P.M.	Volatile, Per Cent Total	Total, P.P.M.	Fixed, P.P.M.	Volatile, Per Cent Total
January	697	414	40.6	266	84	68.4
February	723	455	37.1	223	72	67.7
March	681	418	38.6	230	75	67.4
April	683	430	37.0	220	77	65.0
May	675	382	43.4	245	68	72.2
June	688	413	40.0	244	92	62.3
July	656	401	38.9	218	64	70.6
August	634	376	40.7	232	79	65.9
September	676	406	39.9	242	86	64.5
October	706	422	40.2	263	78	70.3
November	690	436	36.8	237	75	68.4
December	668	414	38.0	233	76	67.4
Max. Daily	1,169	777	58.8	789	437	92.8
Min. Daily	381	217	25.1	97	10	35.5
Average	681	414	39.3	238	77	67.5

Ardern and Lockett (68) state that of all the tests investigated at Manchester, England, a study of the microscopical characters of activated sludge appears to afford the most valuable information as to its condition. The general appearance of the original fresh sludge is studied under the microscope. The presence or absence of threads is particularly observed and the types of protozoa, present and predominating, is recorded. Based on a microscopical examination, they classify sludge as follows:

Sludge in Bad Condition—
Preponderance of flagellates, amoebae, and other rhizopods; relatively few ciliates, *e.g., carchesium, chilodon, choenia,* absent.

Sludge in Unsatisfactory Condition—
Flagellates, amoebae, and other rhizopods; some ciliates, *e.g., stentor, paramoecia, chilodon, carchesium, vorticella; choenia,* absent.

Sludge in Satisfactory Condition—
Few flagellates and amoebae and other rhizopods: preponderance of ciliates, *e.g., carchesium, vorticella, chilodon, colpoda, colpidium:* some *aspidisca* and *loxophyllum:* occasionally, *choenia:* few *suctoria.*

Sludge in Good Condition, with Nitrification Well Established—
Very few flagellates: amoebae, rare: preponderance of ciliates, *e.g., carchesium, vorticella, aspidisca, loxophyllum, choenia:* few *suctoria.* Very few filamentous mycelium growths.

Operating Routine

Generally at the larger plants the records obtained include the sewage flow, air flow, sludge index, mixed liquor solids, return sludge solids, and suspended solids in the effluent. At Indianapolis (26, 48), the sludge demand and the sludge activity are determined, as well as the dissolved oxygen in the aeration tank effluent. Other operating records are made as listed by Hurwitz (30).

Starting Operation.—The early experimenters accumulated activated sludge rather laboriously over an extended period on the fill-and-draw basis by successive decantations of the supernatant liquid, the sludge being retained. One tank was used to aerate and then settle the sludge. In step with the development of the continuous flow method of operation in the United States came the discovery by Bartow and Mohlman (73) that satisfactory sludge could be obtained in 10 to 14 days in sufficient volume if the plant operated from the start on a continuous flow basis. Today all the larger plants are started in this manner without difficulty. Activated sludge is developed in from 7 to 10 days (Baltimore; Chicago; Houston; Peoria; Springfield; Wards Island, N. Y.). However, as recently as 1937, for small plants in Ohio, Barton (74) advises filling the aeration unit with freshly settled sewage, applying air for a period, settling this liquor, decanting the clear liquid from the final tanks, replacing the decanted liquor by settled sewage, and repeating until activated sludge is accumulated.

Indianapolis Routine.—The basis of the operating procedure of Bloodgood at Indianapolis is a continuous daily graph showing the following:

1. Mixed liquor solids.
2. Return sludge solids.
3. Sludge index (Bloodgood basis).
4. Sewage flow.
5. Air (total cubic feet).
6. Sludge demand (oxygen used per hour).
7. Sludge activity (oxygen used per hour by sludge fed into synthetic sewage).
8. Suspended solids in effluent.
9. Dissolved oxygen at the end of the aeration tanks.

The temperature of the mixed liquor and the detention period in the aeration tanks may also be obtained.

In general a mixed liquor concentration is established which will adequately treat the incoming sewage. The quantity of excess activated sludge wasted is based upon the concentration of mixed liquor solids, which are permitted to vary not over 200 p.p.m. within a relatively short period, such as a week. The return sludge concentration is closely watched.

Springfield Routine.—At Springfield, Larson attempts to maintain the solids in the mixed liquor between 1,500 and 2,000 p.p.m. The dissolved oxygen in the effluent of the aeration tanks varies between 4 and 6 p.p.m., and in the effluent of the final tanks between 1 and 2 p.p.m. The sludge index is calculated daily. Unless the aeration tanks are not functioning properly, the biological growths in the mixed liquor are checked only once a week. A sludge blanket is not maintained in the final settling basins. Larson prefers to return the sludge promptly to the aeration tanks even if it is thin. The quantity of air used is not always a minimum for good purification, because, when the digester gas production is high, it is used by the blower gas engines instead of being wasted.

Hourly composite samples are collected daily of the raw sewage, primary effluent, secondary effluent, and mixed liquor. These samples are not weighted in proportion to the sewage flow. Suspended solids, volatile suspended solids, and the 5-day B.O.D. are determined in the first three samples. The suspended solids and the settleable solids of the mixed liquor are determined to calculate the sludge index. Daily determinations are made of the nitrates in the final effluent and also of the total and volatile solids on a composite sample of raw sludge.

Once a week the following routine is followed. In a grab sample of the returned sludge, the settleable and suspended solids are determined. In grab samples from the raw sewage, primary effluent, and secondary effluent, the temperature, pH, and dissolved oxygen are determined. Once a week or more often if the aerators are giving trouble, the dissolved oxygen is also determined at three points in the aeration tanks.

Tenafly Routine.—At Tenafly, N. J., Vermilye (69) checks over the plant hourly from 8 A.M. to 4 P.M. and every two hours thereafter. This procedure requires ten minutes for each group of observations and includes the sewage flow, aeration liquor concentration, return sludge quantity and density, and sludge blanket depth in the clarifiers. A centrifuge is used for a rapid determination of the solids in the return sludge, and at the inlet and outlet of the aeration tanks. A sludge blanket depth detector (70) is also employed.

The Committee is aware of U. S. Patent No. 2,154,132, issued to E. B. Mallory, for a process of controlling the purification of sewage, and also certain other patents issued to him for sewage purification apparatus, namely, U. S. Patents Nos. 2,204,093, 2,223,257, and 2,223,258. In an article published in *Water Works and Sewerage,* August, 1941, Vol. 88, pages 333–344, he describes his method, which apparently is based on mathematical formulae, in part relating to the concentration, percentage of return sludge, and the proportions of the aerating and settling tanks.

Rockville Center Routine.—Anderson (71, 72) reports that at Rockville Center, L. I., the sludge must settle to less than 20 per cent of its original volume in 10 minutes. He determines the total suspended solids in the mixed liquor and in the return sludge, which average respectively 900 and 12,000 p.p.m. These results are checked by centrifuge tests. The dissolved oxygen varies from a trace to 3 p.p.m., as determined daily in the effluent from the aeration tanks. The B.O.D. and the total suspended solids are also determined daily. The air diffusers are backwashed daily. The aeration tanks are frequently examined for deposits.

Determination of Dissolved Oxygen in Sewage and Activated Sludge Liquors.—In determining the dissolved oxygen in sewage and activated sludge liquors, some caution is needed to obtain accurate results. For liquids containing high amounts of organic matter, Heukelekian (27) suggests the use of a modified Winkler method, in which the period of alkalinization is reduced to a minimum consistent with the reaction. Two ml. each of manganous sulfate and alkaline potassium iodide are added and the bottle shaken for 15 to 20 seconds, when 2 ml. of acid is added without allowing the precipitate to settle. However, this modification is likely to give low results.

Heukelekian (75) further notes the absence from *Standard Methods of Water Analysis* (76) of a method for determining dissolved oxygen in sludge mixtures. Because of the interference of the large amounts of organic matter present, the Winkler or Rideal-Stewart Modification are ruled out. The sludge must be separated and the dissolved oxygen determined on the clear liquor. Sterilizing and coagulating agents have been added, such as mercuric chloride (38) or copper sulfate (31) or sulfuric acid (0.5 ml. of 10 per cent solution to 300 ml.).

To determine the dissolved oxygen in the aeration tank, copper sulfate is commonly used to stop biologic action. Ten c.c. of 10 per cent copper sulfate solution are put in a quart bottle and the sample for dissolved oxygen taken with the aid of a standard sampling can. The bottle is stoppered, shaken, and allowed to settle until 250 c.c. of supernatent liquor can be siphoned off into a dissolved oxygen bottle. The dissolved oxygen is now determined by the azide method at all the plants of The Sanitary District of Chicago. This is a modification of the Winkler method, in which sodium azide is added to the alkaline iodide Winkler reagent. This procedure is recommended in the determination of dissolved oxygen in samples which contain nitrites in large amount. It was suggested by Barnett and Hurwitz (77). Originally the use of sodium azide was proposed by Alsterberg (78). His method was modified by Ruchhoft (79, 80), for laboratory use. The Barnett procedure is simpler and can be used in the field for plant control. Recently Cohen and Ruchhoft (81) have suggested the use of sulfamic acid as a substitute for sodium azide, as a preliminary treatment to remove nitrites in the Winkler test. However, they do not advise its use where river mud, ferrous or ferric iron, sulfite waste, or other oxidizing and reducing agents are present.

Rapid Methods for Sludge Solids.—Smith (82) investigated three methods for the rapid estimation of activated sludge solids for plant control at Chicago:

1. Centrifuge method, which is useful as a rough control test, requiring about 5 minutes.
2. Specific gravity method, requiring from 5 to 7 minutes and more skill in manipulation.
3. Aluminum dish method, involving vacuum filtration, drying, and weighing the solids.

He concludes that the aluminum dish method is the most accurate, as the other two methods are affected by changes in the sludge characteristics in wet and dry weather.

Setter (83) discusses the use of a centrifuge, stating that the deviation of the centrifuge method from the Gooch crucible method ranged from plus or minus 20 to 30 per cent or an average of plus or minus 17.5 per cent, whereas duplicate Gooch filter determinations deviated from the mean by an average of plus or minus 4.39 or a maximum of plus or minus 11.1 per cent.

At various plants, including Indianapolis, Milwaukee, Grove City, Rockville Center, Salinas, and Tenafly, a centrifuge has been used to concentrate the solids and determine the volume. If a graph be prepared from a group of tests, the operator can correlate the sludge volume when centrifuged with the suspended solids by weight, and can determine from the centrifuge test the approximate weight for use in the sludge index.

Sludge Index.—As a measure of the settleability of activated sludge the sludge index has been devised. This index is generally defined as the volume in milliliters of one gram of sludge after settling thirty minutes. The technique recommended by Mohlman (84) is now generally employed (30). The use of the aluminum dish method (82) expedites the determination. This method is employed by The Sanitary District of Chicago at the Calumet and Southwest Works, whereas a bitumen dish is used at the North Side Works. The sludge index is helpful in controlling operation. Donaldson prefers a different sludge index, obtained by dividing 100 by the Mohlman index.

Sludge indices vary on monthly and yearly averages (Table XIII) as well as daily (Fig. 4). Daily and monthly averages would be more informative but space does not permit including them in this report. A general criterion is to keep the sludge index under 100, but at some well operated plants the average yearly index is considerably higher. A rising sludge index may indicate an overload, under-aeration, or a tendency toward bulking. Apparently the volatile suspended solids have a large influence on the sludge index. At Peoria, in general, as the volatile suspended solids increase, the sludge index increases and vice versa.

At the North Side Works, Chicago (Fig. 4), during May, 1935, on daily results, the volatile suspended matter is lowest when the sludge index is lowest, immediately following a moderately heavy rainfall. The sludge index is highest when the volatile suspended matter is highest, after a period of dry weather. The monthly averages for 1936 to July, 1941 inclusive (Fig. 5) show the variations of the sludge index, temperature of final effluent, the per cent of volatile solids in the return sludge, and the rainfall. In general, the sludge index is lowest at the end of winter or in early spring, and rises to a peak towards the end of summer or early fall, usually after the temperature of the final effluent has passed its maximum. The fluctuations of the sludge index synchronize approximately with those of the volatile solids in the return

TABLE XIII.—*Sludge Index at Various Activated Sludge Sewage Treatment Works, Mohlman Index*

Plant	Year	Sludge Index				
		Yearly Average	Maximum Month	Minimum Month	Maximum Day	Minimum Day
Chicago S. D.						
North Side	1936	67	97	52		
	1937	80	137	43		
	1938	73	117	38		
	1939	84	116	53		
	1940	85	119	68	184*	45*
Calumet	1936	38	47	29		
	1937	43	68	29		
	1938	52	86	38		
	1939	49	58	38		
	1940	59	76	46		
Springfield	1936	99	155	56		
	1937	100	230	40		
	1938	171	514	33		
	1939	158	468	38		
	1940	157	370	63	620	41
Peoria	1936	157	250	80		
	1937	137	378	63		
	1938	200	558	84		
	1939	156	302	48		
	1940	158	248	107	675	60
Cleveland	1939	74	157	53	300	33
	1940	63	74	55		
Wards Island	1939	152	250	102		
	1940	128	182	88	257	54
San Antonio	1935	222	364	70	479	30
	1940	233	341	77	468	55
North Toronto	1935	145	209	74		
	1936	130	246	60		
	1937	102	213	45		
	1938	85	169	61		
	1939	110	267	43		
	1940	129	264	67	305	57
Rockville Center	1935	80			171	38
	1936	92			199	40
	1937	118			381	30
	1938	108			250	31
	1939	68			116	42
	1940	49			91	30

* One battery only.

sludge, the sludge index rising as the volatile solids increase and vice versa. However, the peaks do not always synchronize.

At Topeka, Kan., the sludge index is kept under 200, but may rise to 840, according to Haseltine (85). However, high solids in the effluent at Topeka are probably caused by rising sludge due to blood from the packinghouses or to other causes such as the formation of nitrogen gas. Likewise at San Antonio, Tex., where packinghouse waste is present, the average monthly sludge index fluctuates on monthly averages from 70 to 364, and 200 indicates (35) good sludge (Table XIV).

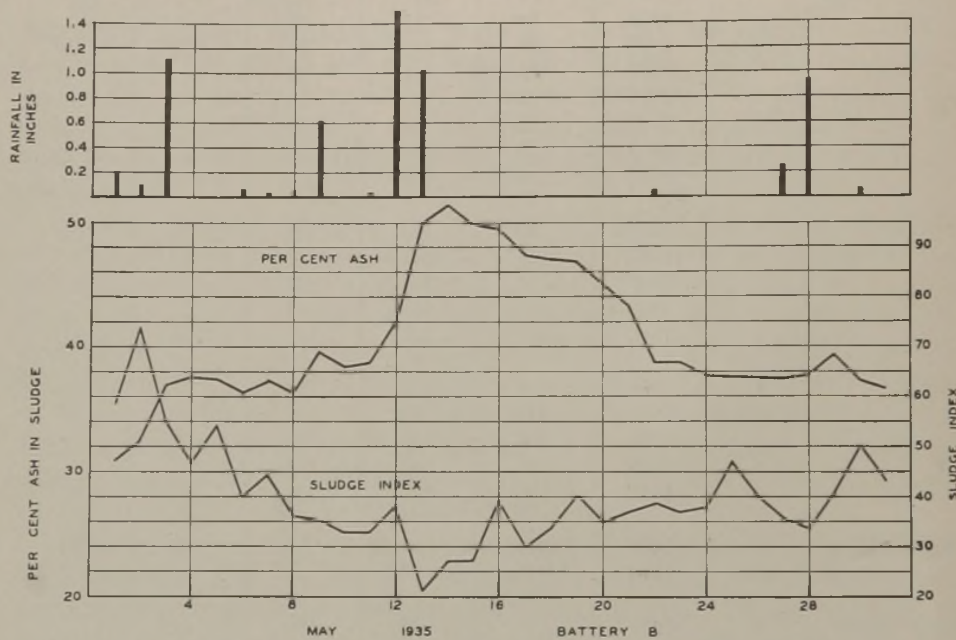


FIG. 4.—Relation between rainfall, ash in sludge and sludge index.

At North Toronto, Ont., the average weekly activated sludge index has varied from 34 to 283, and averaged 110 during 1939. No definite relation was found between the sludge index and the amount of suspended solids in the final effluent. In general, the B.O.D. of the final effluent was somewhat greater during periods of high activated sludge index.

At Peoria, the sludge index is determined daily and to a large degree it is used in regulating the concentration of suspended solids in the mixed liquor. Longley normally operates with about 1,500 p.p.m. of suspended solids in the mixed liquor when the sludge index is around 150.

Sludge Index at Indianapolis.—At Indianapolis, the method used differs from that recommended by Mohlman for determining the sludge index. First, the mixed liquor is adjusted so that it contains 2,000 p.p.m. of suspended solids. It is then placed in a 500 ml. cylinder and allowed to settle. The volumes of solids that have settled are deter-

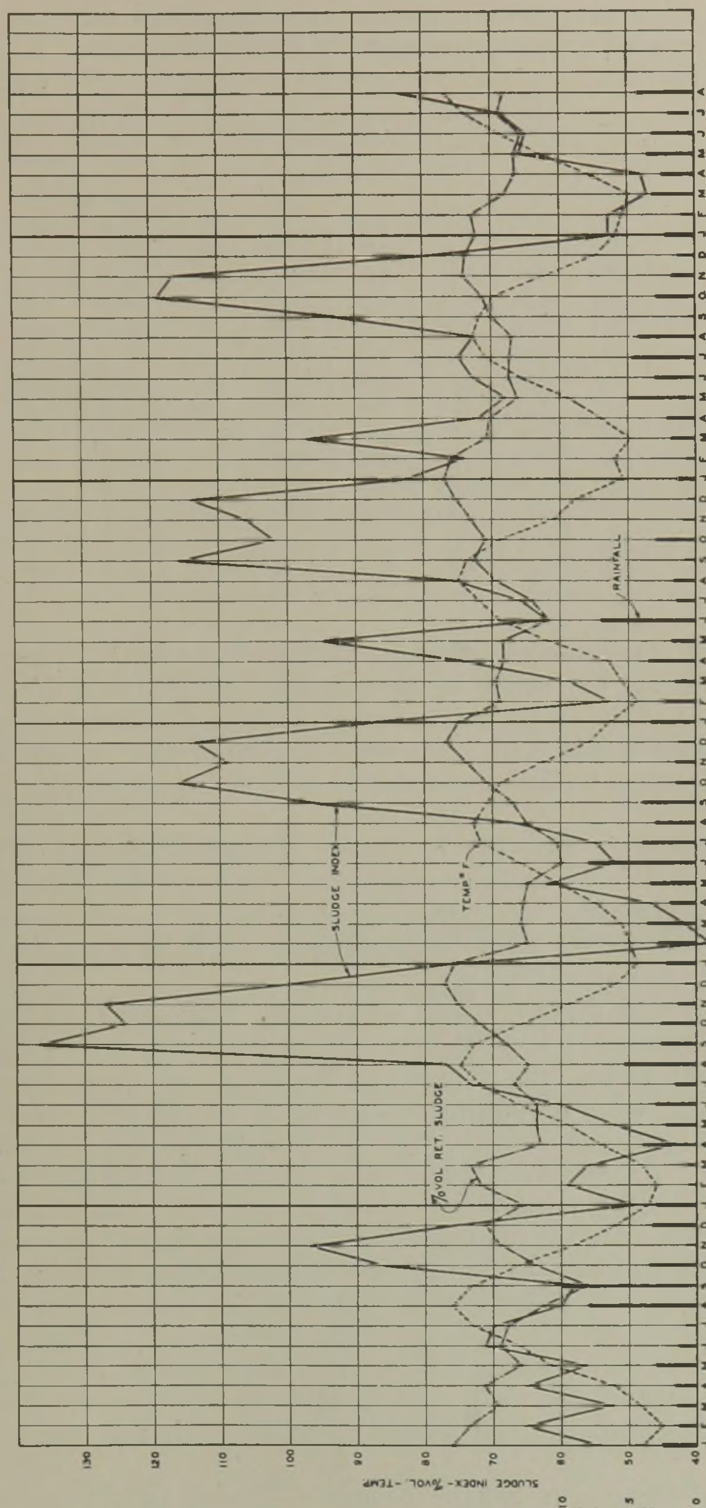


FIG. 5. The Sanitary District of Chicago. North Side Sewage Treatment Works. Per cent volatile return sludge. Sludge index. Temperature final effluent. Rainfall.

Table XIV.—*Performance of San Antonio Sewage Works, 1935*

Month	Raw Sewage		Air, Cu. Ft. per Gal.	Aeration Period, Hr.		Mixed Liquor, P.P.M.	Sludge Index	Per Cent Return Sludge	Return Sludge, Per Cent	
	Total Solids	Susp. Solids		Aeration Tank	Reaeration Tank				Solids	Vol.
January....	837	313	0.92	7.26	0.94	2,400	268	54.0	0.46	73.4
February...	786	263	0.89	7.12	0.97	1,700	364	50.1	0.39	73.1
March.....	846	310	0.92	7.18	0.94	2,000	363	53.0	0.48	72.8
April......	931	297	0.83	6.79	0.95	1,900	215	47.9	0.47	72.1
May.......	1,071	241	0.83	6.89	1.03	2,200	86	43.8	0.51	69.7
June.......	1,205	208	0.81	7.03	1.15	1,600	70	38.2	0.35	65.8
July.......	1,152	243	0.74	6.13	0.96	2,100	205	40.6	0.46	67.9
August.....	1,115	231	0.77	6.33	0.96	2,100	164	42.6	0.47	70.5
September .	1,099	239	0.74	6.08	0.95	2,100	171	40.9	0.51	71.6
October....	1,179	246	0.73	6.06	0.94	2,000	185	41.2	0.54	73.4
November..	966	262	0.79	6.31	0.94	2,300	235	43.8	0.54	75.2
December..	1,104	279	0.76	6.20	0.95	2,000	310	41.7	0.53	73.7
Average....	1,024	261	0.81	6.58	0.97	2,000	222	44.4	0.48	71.6

mined at 5-minute intervals, during a period of one hour. There is always one gram of dry solids in the cylinder. By dividing this weight by the volume of the sludge at the end of an hour the sludge concentration is obtained in per cent. The operating procedure is that the return sludge concentration must not exceed the concentration of the sludge index.

Sludge Index in Relation to Excess Sludge.—Edwards (61) has studied the relationship between the sludge index and the percentage of solids and volatile matter in the excess sludge at Wards Island and Tallmans Island (Table XV). As the volatile solids increase, the sludge index (Mohlman) also increases.

Rate of Sludge Return.—The present day tendency is to keep the sludge blanket at a low level in final settling tanks and store the sludge in the aeration tanks, thus reducing the detention period of the sludge in the settling tanks. This procedure may avoid septicity, which may be evidenced by rising sludge. A stale return sludge may contribute to bulking (86). At the North Side Works, Chicago, Palmer (39) does not keep a deep sludge blanket, as it tends to become septic, but maintains a depth of a few feet in the final tanks and increases the rate of sludge return as the sludge index increases. He favors the use of small air lifts in final settling tanks to indicate the depth of the sludge. Barton (87) states that a considerable depth of sludge may be detrimental and may require more air in aeration tanks to maintain optimum biological conditions. A thick blanket may cause trouble by lowering the dissolved oxygen, thus destroying the biological equilibrium and resulting in bulking.

Dissolved Oxygen in Sludge Blanket.—Heukelekian (27) believes

TABLE XV.—*Relationship Between Sludge Index and Percentage of Solids and Volatile Matter in Excess Sludge, Wards Island, N. Y. (1939)*

Per Cent Solids	Per Cent Volatile	Sludge Index		No. of Observations
		Donaldson	Mohlman	
2.67	64.8	1.09	91.8	1
2.70	68.5	0.84	119	26
2.38	72.8	0.75	133	118
2.23	77.2	0.63	159	153
2.02	81.6	0.45	222	59
1.91	85.5	0.40	250	2
Weighted Average 2.27	75.9	0.66	151	
Tallmans Island, N. Y. (Sept., 1939–May, 1940)				
8.84	38.1	2.6	38.5	6
6.40	41.9	3.3	30.3	16
5.68	47.9	2.2	45.5	19
4.49	52.9	1.9	52.6	39
4.10	57.5	1.7	58.8	52
3.56	62.6	1.4	71.4	71
3.52	67.0	1.4	71.4	39
3.27	71.6	1.4	71.4	13
2.81	77.0	1.2	83.3	3
Weighted Average 4.23	58.5	1.7	58.8	

From Edwards (61).

that dissolved oxygen in a settling tank effluent does not guarantee that anaerobic conditions are not present in the sludge.

Septic Sludge a Detriment.—Obviously, the return of deoxygenated or septic sludge to aeration tanks is a detriment.

Sludge Level Indicator.—In the plants of The Sanitary District of Chicago, a sludge level indicator is set in each tank, consisting of three small air lifts pulling from different depths. At Indianapolis Bloodgood (87a) uses a portable sludge blanket detector and turbidimeter operated by a two-cell flashlight.

Electric Eye.—At Morristown, N. J., Hoffman (88) has controlled the level of the sludge blanket by an electric eye since December, 1932. During the early use of the apparatus, there was difficulty in obtaining watertight photo-electric cells. This device regulates the return of the sludge. The use of an electric eye for both an indicator and for control was also tested by The Sanitary District of Chicago, beginning in 1927 at the Des Plaines River Works at Maywood and in October, 1933, at the North Side Works. Trouble was experienced in keeping the glass windows clean, which protect the cell and light source, to prevent the cell reacting in clear liquor. Two electric eyes are installed in each final settling tank in Baltimore, Md., but are not used as the sludge is kept below the lower eye.

Control of Final Settling.—At Indianapolis, Bloodgood maintains the sludge from the outlet end of the aeration tank and from the bottom of the final settling tank with a sludge demand based on the Indianapolis test within 5 p.p.m. of each other. If the difference is greater than this amount, the sludge from the settling tank is usually the higher. This indicates the sludge is held too long in the settling tank to secure the best results.

Sludge Reaeration

Because of the large proportion of packinghouse wastes, in that it tends to control bulking, Haseltine (85) considers sludge reaeration of value at Topeka, Kan. With the exception of the Houston and San Antonio plants, there are very few large sewage plants in the United States equipped with reaeration tanks. At the Calumet Works, Chicago, units are available for reaeration if needed, but as yet no operating data are available.

Berg (89) considers reaeration to be helpful at San Antonio because of a wide variation in flow and in the final settling period. From 5 A.M. to 10 A.M. the average detention period in the final settling tanks is very long—around 7.5 hours. From noon to 9 P.M., the period is much shorter—2.9 hours, which is preferable.

Ruchhoft and Smith (90) note in experiments that prolonged aeration without food (sludge reaeration) altered the nominal characteristics of activated sludge to a point where the aerated sludge lost entirely its ability to oxidize sewage at high rates.

Ruchhoft, Butterfield, McNamee, and Wattie (6) also note that sludge reaeration may not always be a proper corrective measure. Reaeration may be harmful if the food for the bacteria is lacking and the oxidation adsorption equilibrium is upset. In their opinion long aeration periods should be avoided when treating weak sewages. The ratio of sludge to sewage and the aeration period must be carefully adjusted to maintain the sludge in a state of optimum activity for maximum B.O.D. removal and economical operation. The air should be adjusted to the minimum necessary to maintain such conditions. As long as sufficient air is used to keep all the sludge suspended and dispersed throughout the liquor and to satisfy the oxygen requirements of the aeration mixture, the exact quantity is unimportant from the standpoint of sludge adsorption and oxidation efficiency.

Bottcher (91) confirms the possibility of harmful effect caused by reaeration when the oxygen requirement of the sludge falls too low and the substrate oxidation capacity falls also.

Bulking of Activated Sludge

In the 1937 report of this Committee (92), the information then available on bulking of activated sludge was summarized. The additional material published since confirms the general conclusions of the report that bulking is traceable to overloading by an increase in the volatile solids, by under-aerating, or by excessive growths of *Sphaerotilus*.

Ruchhoft and Kachmar (93) have recently concluded that bulking is primarily due to a sudden increase in loading and that *Sphaerotilus* is only a symptom and not a cause. They point out that bulking involves several factors; oxygen supply, food concentration, sludge concentration, sludge condition, carbon-nitrogen ratio, temperature, and nitrate content. Whereas the belief is common that carbohydrates induce bulking, Ruchhoft and Kachmar indicate the majority of cases do not involve the presence of excess carbohydrates. In their opinion a sudden change in the sludge, food, or oxygen supply may cause bulking. The biophysical misadjustment may be due to a sudden change in operating conditions. Heukelekian and Ingols (93) agree with Ruchhoft and Kachmar that "whatever the mechanism of bulking, however, it is definite that bulking is brought about by the improper balance of food, sludge, and oxygen." However, Heukelekian and Ingols believe it possible that *Sphaerotilus* is not a primary cause. They do not consider the hypothesis is proven.

Heukelekian and Ingols (94) reproduced bulking in the laboratory. In determining the rate of bulking, they note the following factors:

"1. With a given sewage load and sludge concentration, the ratio of bulking is dependent upon the quantity of air or its concentration in the gas mixture.

"2. With a given sewage load and quantity of air, the rate of bulking increases with increasing suspended solids concentration in the activated sludge mixture. With suspended solids beyond certain concentrations, the rate of increase in sludge index decreases.

"3. A more highly oxidized sludge bulks less readily than a poorly oxidized sludge.

"4. The addition of 10 to 20 p.p.m. of nitrate nitrogen prevents bulking.

"5. The stronger the sewage, the more readily it causes bulking.

"6. The higher the temperature, the greater the increase in sludge index.

"7. Reaeration of sludge with a limited oxygenation capacity may result in an increase in sludge index especially with higher sludge concentrations."

In the absence of carbohydrates, a deficiency of oxygen is the important factor. If there is an oxygen deficiency, *Sphaerotilus* becomes predominant over Zooglea.

Bulking in the presence of carbohydrates is also due to the preponderance of *Sphaerotilus*. *Sphaerotilus* utilizes carbohydrates more efficiently and causes a deficiency of food for Zooglea.

Heukelekian (95) defines bulking as a disease, developed under an unfavorable environment, and of a type either slow and cumulative or sudden and explosive. He urges the operator to make microscopical examinations of the sludge and to determine the dissolved oxygen in the aeration tanks and the nitrate in the effluent as an index of thorough aeration and adequate air supply. He summarizes current available remedies as follows:

1st —Reduce the amount of sludge in the aeration tanks.
2nd—Increase the air supply.
3rd—Keep the sludge as fresh as possible.
4th—Dilute the sewage with effluent or surface water.
5th—Chlorinate the return sludge to reduce the high initial rate of oxygen demand.

In acute cases it may be necessary to improve the efficiency of aeration, prevent short-circuiting if it exists and correct any other operating difficulties.

Ely notes (96) that bulking occurs at Ontario, Cal., first, from under-aeration, and, second, from the addition of a foreign substance such as orange syrup or wastes from an "orange by-products plant" which upsets the biological equilibrium. On four different occasions adding finely divided clay corrected the difficulty.

According to Dodge (97) lime and clay proved ineffective in correcting bulking at Ann Arbor, Mich., being beneficial only for one day. New activated sludge had to be developed. At Rockville Center, L. I., Anderson (71) at one time used as much as 150 p.p.m. of dry lime, if more than 20 per cent by volume of sludge settled out in 10 minutes. For the last six years, however, he has not used lime. Haseltine (98) states that in California, at Escondido, Golden Gate Park (San Francisco), Yosemite Valley, Pasadena, and the Los Angeles County Sanitation Districts, hydrated lime was applied to stop bulking. At the last three places the procedure was discontinued as it was very costly or ineffective. At Salinas, Cal., and Grove City, Pa., lime appeared helpful. Haseltine believes lime is beneficial in removing carbonic acid present rather than in adjusting the pH. As aeration is required, lime is sometimes effective when applied near aeration tank inlets. Lime is of no benefit when bulking is due to an inadequate air supply or an insufficient aeration period. Haseltine believes *Sphaerotilus* cannot be destroyed by pH adjustment without impairing biological oxidation. He suggests trying daily applications of 50 to 300 lb. of lime per million gallons of sewage to prevent bulking. If bulking is imminent, 300 to 500 p.p.m. of lime should be applied until the pH approaches 8.0 at the outlet of the aeration tanks. Two or three such treatments on alternate days may be necessary. Usually one treatment will serve for several days.

Bleaching powder and copper sulfate (in one case both simultaneously) were tried by Molitor at Morristown, N. J. (99). Increasing sludge return proved most practical. Reaeration was of slight value.

Bushee (100) concludes that bulking does not occur if the fixed solids in the mixed liquor are more than 25 per cent of the total suspended solids.

Bulking traceable to insufficient air may be corrected by reducing the solid load and increasing the air, provided the necessary air is available.

Berg (35) notes at San Antonio the absence of bulking except when the incoming solids become so great that the air supply is inadequate to furnish the additional air needed. He has definitely found two causes for bulking (101); one, excessive discharge of slaughter house waste; the other, a very strong digester supernatent discharged for several days. He concludes (102) that at San Antonio bulking is wholly due to insufficient air and that the minimum air used should be 1000 cu. ft. air per lb. of B.O.D. removed in the aeration tank. To correct bulking may require over two weeks. The relation between the sludge index, the air used, and the strength of the sewage is shown with other data (Table XIV) for San Antonio in 1935.

When sludge begins to bulk, it may become slimy and malodorous. The color of the algae in the final clarifiers turns from green to pale grey.

Recent facts regarding the biology of *Sphaerotilus Natans* Kutzing and its relationship to the bulking of activated sludge have been published by Lackey and Wattie (103). Whereas *Sphaerotilus* is normally not abundant in an activated sludge plant, bulking sludge frequently contains large quantities. Studies of a pure culture of this organism indicate that it interferes with settling, and requires sugars and organic nitrogen. *Sphaerotilus* also exhibits a wide range of pH tolerance, growing between 5.5 and 8.0. For the control of *Sphaerotilus*, chlorination of the returned sludge is considered most feasible, as chlorine is the cheapest available toxic substance. Fortunately, no substance which stimulates excessive growth has been found in normal sewage. Ingols and Heukelekian (104) state that bulking "produced by carbohydrates is a direct response of *Sphaerotilus* to a relatively long contact with an available energy food."

Ruchhoft, Kachmar, and Moore (105) in studying glucose removal by activated sludge indicate that over-chlorination must be avoided when activated sludge is chlorinated to correct bulking caused by fungus growths. Apparently this procedure may interfere with the glucose removal mechanism, but not seriously when moderate doses of chlorine are used. When a mixed liquor containing about 1,500 p.p.m. of suspended sludge solids was dosed with 1.6 p.p.m. of chlorine, the glucose removal was only slightly affected. With a chlorine dose of 6.2 p.p.m. the glucose removal rate was lowered 75 per cent. With 15 p.p.m. of chlorine the reaction stopped for 4 hours.

Pralle (106) applied 5.34 p.p.m. of chlorine to the return sludge at Houston, Tex., thereby improving the effluent from an overloaded plant and reducing *Sphaerotilus*. Over-chlorination was avoided by suitable control. At Lancaster, Pa., Wiest (107) controlled filamentous organisms in the return sludge by applying 2 to 18 lb. of chlorine per million gallons of sewage until gashouse waste interfered with the operation. On the other hand, Ridenour, Henderson, and Schulhoff (108) report that at an institutional plant at Marlboro Hospital, N. J. (1.3 m.g.d. capacity), chlorine was applied to a bulking sludge full of filamentous organisms. The return sludge was chlorinated up to 72 per cent of the chlorine demand, or 0.46 per cent on a dry solids basis, with no improvement in the sludge index and no change in the filamentous character of the sludge. The purification of the sewage was practically unaffected. The chlorine demand of the sludge decreased throughout the 15-day chlorination period.

Edwards (61) believes chlorine is effective when applied to return sludge, as the use of 1.8 p.p.m. of chlorine at the Wards Island plant in New York City produced a 35 per cent improvement in the sludge index. Over a period of 8 months, the chlorine used averaged 2.5 p.p.m. and the sludge index was 133. At Baltimore, when bulking has occurred for short periods, chlorine has been applied to the return sludge in amount from 1 to 9 p.p.m. Chlorination of return sludge has also been practiced at Lima, Ohio (109), Mansfield, Ohio (110), and Morristown, N. J. (99). On the other hand, Bloodgood believes that at Indianapolis chlorination of the return sludge was of no benefit in controlling bulking.

Bloodgood (48) believes that a high content of volatile solids porduces bulking, but not necessarily because of the high volatile solid content alone, but rather because of a high volatile solids content per unit of treatment plant capacity. The capacity is influenced by the mixed liquor concentration and the detention period in the aerator. By reducing the volume of organic matter being treated, the settling qualities of the sludge are improved at Indianapolis. Anderson (72) at Rockville Center, L. I., corrects bulking by removing or discarding the bulking activated sludge.

At High Point, N. C., 4 p.p.m. of activated carbon applied by Moss (111) to the mixed liquor before entering the aeration tanks aided in eliminating bulking.

Digester Overflow Liquor and Bulking.—Discharging supernatant sludge liquor into the incoming raw sewage is a common procedure which may affect the operation of an activated sludge plant. Berg at San Antonio finds that the additional load from the supernatant liquor causes bulking. Haseltine (115) points out that little trouble ensues if the suspended solids in the supernatant liquor are less than 0.2 per cent; otherwise the primary sedimentation tank may become septic and be covered with gas-buoyed sludge.

If the supernatant liquor is discharged into the primary sedimentation tank, the flow should be at a low, uniform rate. Wisely (86) recommends that a poor supernatant be wasted on a sludge bed or in a lagoon. It is harmful when it is black, gives off a foul, sour odor, contains considerable suspended matter, and show a pH below 6.6. Adding lime to a poor supernatant is helpful (115) at Grove City, Pa., in amounts up to 1 lb. per 10 cu. ft. of liquor.

Whether supernatent liquor from digestion tanks is discharged into primary-sedimentation tanks or into aeration units, an increased oxygen demand may be expected (32).

Sludge Condition and Ash Content.—Haseltine, Voelker (112), and others suggest the use of ash determinations of the sludge as an index of condition, believing that a sludge of relatively high ash content works best. Edwards (61) confirms this fact by data for the Wards Island and Tallmans Island plants (Table XV), showing the relation between the volatile solids and the sludge index. To maintain a constant ash content under all conditions is almost impossible, even where the sewage works serves a separate system of sewers. In The Sanitary District of Chicago, the plants function best when the ash content is high and storms recur at reasonably frequent intervals. During protracted periods of dry weather, the volatile content increases and the control becomes more difficult with a tendency to bulking (Fig. 3). The variation in volatile matter in the raw sewage and activated sludge at the Chicago plants is noted in Table VI.

Gavett (62) at Bernardsville, N. J., noted the value of adding clay to aid settling when the sludge was light, whereas Edwards (61) believes such use of clay or soil is not entirely satisfactory.

Excess Activated Sludge

In many plants, the excess activated sludge is returned to the primary settling tanks, as at Springfield, Ill., and at Ann Arbor, Mich. (97). At Springfield, about 150,000 gal. of activated sludge is wasted daily, but only about 40,000 gal. of sludge is pumped from the primary tanks to the digesters, as the moisture content of the sludge is reduced in the primary tanks.

At San Antonio, Berg (101) states that the return of excess sludge to the primary tanks has not proven satisfactory, since the activated sludge comes in contact with the primary sludge, becomes septic and rises. The floating septic material passes into the aeration tanks and adds to the load.

Concentration of Excess Activated Sludge.—At the Tallmans Island plant, New York City, Edwards (61) notes that excess activated sludge could be concentrated satisfactorily when the sludge was chlorinated sufficiently to maintain at least 1 p.p.m. residual in the overflow. The dose of chlorine averaged 30 p.p.m. based on the volume of the sludge. Based on values from the Wards Island and the Tallmans Island plants, Edwards found the concentration of solids in the excess activated sludge decreased and the sludge index increased as the volatile matter increased. At Wards Island, it is difficult to concentrate the waste sludge to 3 per cent solids content.

At Baltimore, the excess activated sludge is thickened in two small Dorr tanks and then pumped into heated digestion tanks.

The use of chlorine in a thickener has also been suggested by Goudey and Bennett (113) and by Traviani (114), who has used chlorine at Phoenix, Ariz., for a number of years. Haseltine (115) suggests the concentrator be fed continuously throughout the day with sludge direct from the mixed liquor.

Floating Sludge in Final Tanks.—At a few plants (86), *chironomus* flies have laid eggs on the aeration tank walls and the larvae have passed into the final settling tanks and formed cylindrical clumps about 2 inches long and 1 inch in diameter. These float on the tank surface but break up when touched and discharge with the effluent. Application of pyrethrum powder at a rate of 1 lb. per 1,200 gal. of mixed liquor is said to be helpful.

Septic Conditions.—If septic conditions develop in aeration tanks, adding lime to raise the pH above 7.0 may help (86). By-passing the sewage around the aerator may be beneficial. Possibly either the sludge blanket in the final settling tanks should be lowered or the air increased in the aeration tanks, or both should be tried.

Rising Sludge.—At the Bruma Sewage Works in Johannesburg, South Africa, a phenomenon has been observed by McLachlan (116) which he describes as "rising sludge." It is characterized by the separation of large flocs from the settled sludge, which in rising may cause the whole sludge to rise to the surface. It is light in color, of loose texture and low density. Filamentous growths are not excessive. Protozoa are restricted in variety and less active than normal. The release of minute gas bubbles is pronounced. O'Shaughnessy and Hewitt (117) trace this action to a reduction of nitrates in the absence of dissolved oxygen in a highly nitrifying sludge with the liberation of gaseous nitrogen. The experiments of McLachlan indicate that a rising sludge may result from the overpowering of good reconditioned sludge by a stronger sewage than usual. Rudolfs (118) suggests that the bubbles of gas may be carbon dioxide or nitrogen. A mixture which promoted the coalescence of the gas bubbles produced a rapid rising. McNamee adds that in a plant producing a nitrified effluent, short circuiting might bring together the two ingredients necessary to produce nitrogen gas, and consequently the sludge rises in the final settling tanks, as the dissolved oxygen decreases. Haseltine (85) notes the occurrence of rising sludge when treating packinghouse wastes. He suggests increasing the solids in the aeration tanks. Similar difficulty with rising sludge was encountered at Sioux Falls, S. D., by Bragstad and Bradney (119).

Effect of Temperature and Grease on Operation

In the northern half of the United States activated sludge plants are more efficient in summer than in winter. Ordinarily, the warmer raw sewage is not troublesome unless it becomes stale or septic. Increasing the aeration period and the rate of sludge return may be helpful (86).

Sawyer and Rohlich (121) studied the influence of temperature upon the rate of oxygen utilization by activated sludge and activated sludge-sewage mixtures obtained from four different sources, under both summer and winter operating conditions. The results were fairly uniform. For activated sludge alone, the average rates at 20, 15, and 10 deg. C. were found to be 71, 45.2, and 25.5 per cent respectively of the rate at 25 deg. C. Activated sludge-sewage mixtures gave rates of similar magnitude, which averaged 73.4, 46.1, and 24 per cent of the rate at 25 deg. C. The influence of temperature was the same, whether nitrification occurred or not. The temperature had the same effect on nitrogen and carbon oxidation. Winter sludges from all sources used more oxygen at a given temperature than corresponding summer sludges.

When the temperature in the aeration tanks drops below 46 deg. Fahr., the sludge activity is reduced and the effluent deteriorates.

Grease.—Mahlie (122) discusses oil and grease in sewage along general lines. Ingols (113) states that the activated sludge process is effective in oxidizing grease, as fats may form over 50 per cent of the material used for energy by the activated sludge when aerated with sewage. As a result, the grease content of the sludge is considerably lower than that of the suspended solids in the raw sewage. Haseltine (115) suggests that the process functions well with a grease content in the sludge ranging from 5 to 7 per cent. At 13 per cent, operation becomes difficult, and at 30 per cent, loss of clarifying power may produce a poorer effluent. The grease should be removed, if excessive.

Haseltine (85) states that grease upsets seriously the operation of the Topeka, Kan., activated sludge plant, where the content of grease is about 60 p.p.m. in domestic sewage; in combination with packinghouse waste, 116 p.p.m.; and in packinghouse waste, 1,481 p.p.m. The detrimental effect of grease on activated sludge processes has also been pointed out by Eddy (123), Oeming (124), and Sierp (125).

Degreasing of sewage has been practiced in a number of activated sludge plants by aerating the sewage for a short period in a channel or tank ahead of the preliminary settling tanks. This method was modified by Faber (126) at Woonsocket, R. I., who introduced chlorine into the air line serving the separation tank. He reported an increase in grease removal from 189 to 442 per cent (based on pounds of wet scum removed per m.g.) on daily tests for a week, using 1.5 p.p.m. chlorine based on sewage flows, and an average detention period of 6 minutes. Keefer and Cromwell (127) at Baltimore, Md., confirmed the value of chlorine in such degreasing, showing with 2 p.p.m. of chlorine an increase of 149 per cent (based on dry scum) with a 5-minute detention period and 213 per cent with a 10-minute period. With 3 p.p.m. chlorine the increased yield was 327 per cent for a 5-minute period and 231 per cent for a 10-minute period.

At Lancaster, Pa., Wiest (107) found a return sludge with a grease content of 21.6 per cent at the South plant and 5.0 per cent at the North plant. By the introduction of 2 p.p.m. chlorine into the raw sewage ahead of the pre-aeration channel, a 64 to 74 per cent reduction in the original grease content (dry basis) in the return sludge at the South plant was accomplished.

Diffuser Plate Clogging

The installation and servicing of porous air diffusers for activated sludge plants was discussed in 1934 by Roe (128) in detail. To supplement this, inquiry has been made at a number of plants to learn of actual practice. The tendency in the past ten years has been in general to use coarser diffuser plates, with a higher degree of permeability. From about 1920 to 1925, plates were used having a permeability around

10 to 15 cu. ft. per min. per plate at an air pressure of 2 inches of water, whereas plates with a permeability around 35 to 45 have been used of late years. In addition, the working rate of passage of air through the plates has been greatly increased with the coarser plates. At the North Side Works, Chicago, over 90 per cent of the original plates (with a permeability around 12 to 15 cu. ft. per min.) are still giving satisfactory service without any cleaning since installation in 1928. At Springfield, Ill., Larson reports the original plates show no sign of clogging after 12 years' use, without cleaning. At the Calumet Works in Chicago, the clogging was marked after 5 months' use. At the Southwest Works, also, clogging occurred within the first two years of use, which has necessitated cleaning at more or less frequent intervals. Other works report somewhat similar occurrences. The exact cause of the clogging is not always known.

At the Calumet Works, it appears that unusual amounts of ferrous salts in the sewage, averaging from 2 to 32 p.p.m. Fe on daily averages, and with hourly content as high as 290 p.p.m., due to spent acid pickling liquors from steel mills and foundries, resulted in a deposit of ferric hydroxide in the top surface of the plates, causing a rapid increase in the air pressure. At the height of the trouble the aeration tanks were drained in rotation every two to three weeks and the surface of the plates cleaned with dilute hydrochloric acid or a mixture of chromic and sulfuric acid, and then brushed. Such treatment was effective for two to four weeks in a tank with a single row of diffusers, and for three to six weeks in a double row tank. Placing a 6-inch layer of crushed limestone, sieved between 2 to 3 inches in size, on top of the plates proved helpful, increasing the period between cleanings to between eight and twelve months, although occasionally only one month. As the pickling liquor wastes were gradually diverted from the sewers, the daily average content of iron in the sewage decreased below 12 p.p.m., the frequency of cleaning was greatly reduced, roughly, from intervals of two weeks to six months or more. Of late the period between cleaning has again shortened to about one month.

At the Southwest Works, the iron content has been moderate but clogging persists after cleaning and the diversion of the pickling liquor.

Calumet Works.—At the Calumet Works, various tests were made on unit tanks, including the atomizing of caustic soda solution into the air header, as well as a solution of phenol and kerosene and a solution of copper sulfate. Emptying the tank and drying out the plates was also tried. All these methods proved futile. The only satisfactory method was to drain the tank and cover the diffusers several times with concentrated hydrochloric acid. This worked well but was hard on the cement joints. Later a cleaning solution of concentrated sulfuric acid and sodium dichromate was used, which proved better than the hydrochloric acid. However, the most effective solution was found to be equal parts of water and sulfuric acid, to which is added sodium dichromate. Joint material composed of 1 part Portland cement and 2 parts silica sand, and of 1 part lumnite cement and 2 parts silica sand are under trial, in place of a lean mortar of one part Portland cement and 1 to 1½ parts of sand. So far no satisfactory bitumen or asphaltum joint material has been found.

Southwest Works.—At the Southwest Works, the plates began to clog after 18 months of use. At first wire brushing was tried. In another tank hydrochloric acid was used, and in another, two applications of nitric acid. Other plates were treated with two applications of chromic acid, followed by one application of sulfuric acid. About three-fourths of these plates were given an application of nitric acid before the application of chromic acid. After one month's interval, one of the tanks containing wire-brushed plates received a treatment of two applications of nitric acid. Later all the plates in one battery were given two applications of nitric acid, and the plates in the influent channels received three applications. Apparently these treatments give temporary relief.

Indianapolis.—In 1940, clogging reached a critical point at Indianapolis. The removable plates were taken out and boiled in 6 per cent caustic for five hours, washed in water and submerged in 10 per cent muriatic acid for 18 hours.

Cleveland.—The Easterly plant (129) was put in operation in September, 1938. In 1939 the plates began to clog. The following acids were tried: nitric acid (38 deg. Be. used as such); muriatic acid (18 deg. Be. used as such); and sulfuric acid (66 deg. Be.). A solution of sulfuric acid mixed with two or five per cent dichromate of soda was also tried. The plates were taken out, soaked in the acid or solution for several hours, drained, and rinsed in water. Repeated rinsing proved desirable. Nitric acid was no better than muriatic acid. The chromic-sulfuric acid solution (2 per cent dichromate of soda) proved the best cleaning agent.

In a second series of tests, plates were first soaked in muriatic acid, washed, dried, and tested, then washed in gasoline and retested. Muriatic acid produced only a minor cleansing effect. Secondary washing in gasoline had no effect. Other plates were first soaked in gasoline, dried, tested, and then treated in muriatic acid for one hour. The benefits were slight. Another lot was treated with nitric acid for two hours, with slight benefit. Other plates were soaked for one hour in a two per cent solution of dichromate of soda in sulfuric acid, then washed, dried, and tested. The benefit was appreciable, but not sufficient to restore the original permeability. Treatment for a longer time showed no benefit. Other lots, soaked in muriatic acid for 1, 1½, and 2 hours respectively, showed no difference. No benefit accrued by a treatment with muriatic acid for one hour, followed by one hour with chromic-sulfuric acid solution over the chromic-sulfuric acid combination alone. Two hours in chromic-sulfuric acid solution followed by repeating the cleaning process showed a slight additional benefit.

Caustic soda (20 per cent solution) was not so effective as the chromic-sulfuric acid solution. An exposure of 2 hours helped somewhat. The use of caustic soda for 18 to 24 hours, followed by rinsing and the application of chromic-sulfuric acid solution for 2 hours, proved satisfactory.

The conclusions reached at Cleveland were that the chromic-sulfuric acid solution was the only satisfactory agent to restore the porosity of diffuser plates. Five per cent of dichromate was somewhat more effective than 2 per cent. The treatment recommended was to use a 2 per cent solution, soak for 1 or 2 hours, drain, wash, and rinse 10 times.

Peoria.—After ten years' operation at Peoria, Kraus states that the plates in two of the four batteries have never been cleaned. In No. 2 battery, the plates were cleaned after nine years of use. In No. 1 battry, the plates have been cleaned four times. For the first three times, brushing the plates with hydrochloric acid proved effective, but not the fourth time. Instead, the plates were first washed and brushed with water, and then with hydrochloric acid. The plates were then blown dry, and the air was shut off. Concentrated sulfuric acid was then applied. The air was off for 15 minutes, then turned on and the plates washed with water. Sometimes the sulfuric acid treatment had to be repeated. Practically all but a few plates in Battery No. 1 then functioned again at available pressures. After a lapse of one year, clogging is recurring in both Batteries Nos. 1 and 2. Once a week the air pressure is reduced by lowering the water level in those batteries and allowing them to receive a large volume of air for 2 hours. After two such treatments the loss of pressure was lowered 0.3 lb.

Milwaukee.—Ferebee states the original plant in Milwaukee started operation in 1925 and reached full operation in 1926. The rating of the diffuser plates ranged from 9 to 12. The coarser plates were placed in the southern half of the aeration tanks. These are still operating satisfactorily. Around 1931, the top ⅛-inch of these plates was spalled off by the use of blow torches. The finer plates were placed in the northern half of the aeration tanks. With the exception of two tanks, these have been entirely replaced by plates rating from 16 to 21. The Milwaukee experience is that only Filtros plates can be burned off or spalled with blow torches.

The new plant extension went into service December 3, 1935, equipped with plates rating between 32.7 and 36.9. Even though operating at the low rate of 1 cu. ft. per min. per plate, clogging has increased to a point where an additional row of plates rating from 50 to 60 must be added to the present two rows before next summer and then gradually all the existing plates rating from 32.7 to 36.9 must be removed and replaced with plates of the 50 to 60 rating.

The clogging does not appear to be due to soot. The cause of the trouble is being sought.

Houston.—At Houston, Tex., Pralle states the diffuser plates were originally cemented with sulfur into cast-iron holders. In a few months, iron rust from the holders clogged the plates badly. The iron holders were replaced by concrete holders in 1919–1920. The plates were cleaned by immersion in hydrochloric acid (10 per cent solution).

These plates were kept in use until 1936, by drying a tank at a time and spalling the plate with a blow torch. From 1936 to 1937, all the original plates were replaced by diffusers rating around 40 cu. ft. per minute.

Elyria.—At Elyria, Ohio, Jones and Collier (130) report clogging of diffuser plates during intermittent tests on the aeration tanks at the start. Two or three discharges of iron waste per day, up to 400 p.p.m. Fe, flowed to the plant and precipitated in the pans holding the diffuser plates. After starting the plant on a continuous basis, clogging occurred. The tanks were drained, the iron flushed from underneath the diffusers, and some diffusers were replaced. As the discharge of iron continued, the westerly interceptor carrying half the sewage flow and all the iron was diverted to the river. The condition of the plates gradually improved and returned to normal. In the last six months of 1930, the iron in the raw sewage averaged 5.6 p.p.m. and ordinarily is under 15 p.p.m., with an occasional maximum of 80 p.p.m. The settled sewage contained an average of 3.9 p.p.m. and the final effluent 0.7 p.p.m. Later Collier (87) reports that the carborundum plates were cleaned with an oxyacetylene blow torch, by spalling off the clogged top layer. A gasoline torch was used successfully in spalling the Filtros plates.

Decatur.—Hatfield states that at Decatur, Ill., considerable plugging of the diffuser plates has occurred from organic growth on the surface of the plates. For temporary cleaning, concentrated muriatic acid proved best, although the chromate-sulfuric acid cleaning mixture is satisfactory. Because of an intermittent air supply, the plates in the reaeration tank became so badly clogged that they were removed from the tanks, dried, burned to red heat in an oven to destroy the organic matter, and then set in muriatic acid to dissolve the mineral residue. This treatment restored the plates to approximately between 95 and 98 per cent of the original porosity, namely, 16 to 20 cu. ft. per minute. The other plates only received the acid treatment. Resting the plates is helpful, whether in the air or under water.

Charlotte.—Franklin (131) indicates that at the Irwin Creek plant in Charlotte, N. C., the diffuser plates clogged badly. Scrubbing with muriatic acid was helpful temporarily, but on two out of five units, the effect lasted only a few weeks. For eight days chlorine gas was added to the air headers, using about 17 lb. per day to an air delivery ranging from 400 to 800 cu. ft. per min. This increased the delivery about 66 per cent with one blower in service and 53 per cent with two.

Ontario.—At Ontario, Cal., Ely (96) reports a sudden rise in pressure from 4.5 to 8 lb. per sq. in., due to oil and smoke in the air from smudges in the orange groves in January. By feeding gasoline into the air main in small amounts and increasing the air flow, the trouble disappeared.

Ohio.—Clogging has been noted (32) at some of the smaller plants in Ohio. One operator reports that grease frequently applied to diffusers lessens clogging by iron deposits. However, at the Southwest Works in Chicago, grease proved of no benefit.

TABLE XVI.—*Iron Content of Various Municipal Sewages*

City	Year	Iron as Fe in P.P.M.				
		Yearly Average	Monthly Average		Daily Average	
			Max.	Min	Max.	Min.
Akron, Ohio	1929	10–12[d]				
Cleveland						
Easterly	1938	12				
	1939	16.6	22	11	65	2
	1940	13.6	18	10	58	1
Westerly	1936	8.7	18.0	4.2		
	1939	15	23	11		
	1940	13.3	16	10		
Southerly	1936	15	28	6		
	1937	80	40		280	
	1939	150	311	79	1600	15
	1940	59	113	33	280	8
Clinton, Mass.	1930	2.2				
Columbus, Ohio	1940	(f)			4	0
Fort Worth	1937	2.6–8[d]				
Fostoria	1928	95			425	14
	1929	77			966	8
	1930	22.6				
Houston	1937	8				
Indianapolis	1931	3.1				
	1932	2.8				
	1933	3.0				
	1934	3.0				
	1935	2.2				
	1936	1.6				
Milwaukee	1933	6.3	12.6[a]	2.5[a]		
	1934	7.3	14.3[a]	3.2[a]		
	1935	5.6	14.7[a]	3.3[a]		
	1936	10.0	48.0[a]	4.2[a]		
	1937	12.1	42.6	4.6		
	1938	14.3	66.6	4.0		
	1939	20.6	108.0	5.5		
	1940	11.8	38.0	4.8		
	1941	14.3[f]	27.8	6.0		
New Britain	1937	9				
	1938	9				
	1939	21				
Peoria	1941	0 to 8[d]			5.8	
Worcester	1940	25.8				
Chicago						
Calumet	1936	17				
	1937	13	15	7	32	1
	1938	4.5	5.3	3.8	12	2
	1939	4.2	5.2	1	12	1
	1940	5.5	7.2	3.6	21	2
	1941	6.4[b]	8.0	5.1	17	2
North Side	1941	4.36[e]				
Southwest	1941	5[c]			11	2

[a] Weekly composites.
[b] Period of 7 months.
[c] 3 months.
[d] Occasional samples.
[e] 18 days.
[f] 8 months.

Iron Content of Sewage

The iron content in the raw sewage varies at different activated sludge plants from 1.6 to 17 p.p.m. on yearly averages (Table XVI). The higher contents of iron are usually traceable to the presence of spent acid pickling liquors. Usually, where troublesome, such liquors are frequently diverted from the sewer system. The fluctuations which may occur are shown in the data for the Calumet Works (Table XVI). In 1936, the iron was high but the effect did not became marked for five months. When the iron was closely watched in 1937, five different months showed a maximum hourly content of 200 p.p.m. or higher. A policy of diversion reduced the averages and the fluctuations in 1938 and in 1939. The averages rose slightly in 1940, as did the maximum. In 1941, a further increase shows.

Apparently activated sludge plants receiving sewage low in iron have had little trouble with clogging of diffusers. At Indianapolis, however, occasional slugs of iron are noted, running as high as 20 p.p.m. in ferrous iron.

Iron Content of Sludge.—The iron content of the dried activated sludge has been noted at Chicago, Indianapolis, and Milwaukee (Table XVII). In general, the lower the iron in the raw sewage, the lower the content of the sludge. At the Calumet Works, the activated sludge

Table XVII.—*Content of Iron Oxide in Various Activated Sludges, Yearly Averages*

Plant	Date	Per Cent Fe_2O_3 in Dry Sludge	Raw Sewage Fe, P.P.M.
Chicago			
New Calumet	1936	16.4	
	1937	15.2	13.0
	1938	8.7	4.5
	1939	8.0	4.2
	1940	8.1	5.5
	1941[a]	10.7	6.4
Old Calumet	1928–1930	11.1	
North Side	1930	3.1	
	1932	2.7	
	1936	6.1	
	1938	3.5[c]	
	1939	2.35[e]	
	1941		4.36[f]
Southwest	1940	4.3[b]	5[d]
Indianapolis	1932	7.2	2.8
Milwaukee	1931–1932	8.0	
	1933–1936		7.3

[a] Period of 7 months. [b] 4 days. [c] 12 days.
[d] 3 months. [e] 9 days. [f] 18 days.

filtered more easily when its iron content was higher, before the iron-bearing liquor was diverted from the sewer system.

Industrial Wastes

Industrial wastes may be a factor requiring attention in plant operation, depending on the type and concentration. Heisig and Brower (132) have indicated the general rules followed by the Milwaukee Sewerage Commission in attacking the disposition of industrial waste from the standpoint of prevention and the removal of wastes from the sewerage system to benefit plant operation:

1. Removal of such solids as tend to deposit in sewers.
2. Removal or pre-treatment of wastes containing active chemical ingredients, which through their activity result in destruction of sewer structures.
3. Removal or pre-treatment of wastes which may be deleterious either to the purification process or the plant structures.
4. Removal from wastes of all free oils, greases, tarry, and resinous substances.
5. Removal of wastes from sewers which may by their presence result in injury or death to men engaged in active sewer work.
6. Isolating from sewage such solids as are eliminated in process and later are discharged to the sewer as a means of disposal.
7. Removal of all contaminated waters from the general sewage flow, where storm waters are available.

Fales (133) and Oeming (124) discuss the effect of various industrial wastes on municipal sewage treatment works. Rudolfs (134) surveys recent developments in the treatment of industrial wastes. In these articles of broad interest are special references to the effect of industrial waste on activated sludge plants.

Among the wastes which may become troublesome to the activated sludge process if present in sufficient concentration may be listed:

Acid Pickling Liquor.—The waste acid pickling liquor from the steel and foundry industry has upset operation at the Calumet Works, Chicago, and at Elyria, Ohio (130), through promoting the clogging of diffuser plates.

Brewery Wastes.—Stanley (135) reports that brewery wastes were troublesome at San Antonio, Texas. Plain sedimentation for one hour is helpful before discharge into a sanitary sewer, but sedimentation plus liming is desirable.

Cannery Wastes.—At Lodi, Cal., wastes from the canning of fruit and vegetables are kept out of the sewers, to avoid upsetting the activated sludge plant. In some of the smaller towns in California even the waste from home canning of fruit and vegetables upsets the process and makes the effluent cloudy and the sludge nonsettleable. According to Ryan (136), the activated sludge process is not suited for the treatment of mixtures of sewage and cannery wastes.

Citrus Industry.—At Ontario, Cal., Ely (96) reports difficulty with wastes from a citrus by-products plant, causing bulking.

At Pomona, Cal., boron used in washing citrus fruit enters the sewage. As low as 0.05 p.p.m. affects the activated sludge process and prevents the settling of sludge. After the boron flow stops, from two to three hours are required before the sludge settles. If one p.p.m. be present, from one to two days are required for recovery. A city ordinance prohibits the discharge of boron into the sewers, not only because of its effect on the activated sludge process, but also upon irrigated land, where crops are grown.

The Texas State Department of Health (137), however, found wastes from canning citrus juice could be handled alone or mixed with sewage.

Chromium Acid Wastes and Cyanides.—At Mineola, N. Y. (138), chromium acid wastes and cyanides have interfered with the operation of the activated sludge plant.

Copper Salts.—At Muskegon Heights, Mich. (30, 124), New Haven, Conn. (139), and Ann Arbor, Mich. (97), the effect of copper salts has been studied. In general, copper tends to inhibit bacterial growth.

Distilleries.—The operation of illicit stills on the sewer system tributary to the Des Plaines River Works, Chicago (140), practically wrecked plant operation. The waste sugar entering the sewer promoted luxuriant growths of *Sphaerotilus* and in turn caused bulking at the plant. The only satisfactory control was the complete removal of the waste by diverting the particular sewer direct to the Des Plaines River. The final chapter was written with the destruction of the stills by the Federal revenue agents.

Milk Wastes.—Milk waste from dairies in Somerset, Pa., and New Bremen, Ohio, have been treated by the activated sludge process, according to Montagna (141). The waste is first treated with lime to a pH 8 to 9, and given primary sedimentation with recirculated primary sludge. Aeration proceeds for 24 hours, lowering pH to 7.6–7.8, with the use of 2.8 cu. ft. per gal. of waste.

Oil.—Mineral oil has occasionally interfered with the activated sludge process in the aeration tanks at the North Side Works, Chicago Usually the oil comes suddenly in a shot or slug. The efficiency of aeration is reduced. It is possible that there may be some toxic effect on the biological organisms (142). Stanley notes that oil prevented building up of activated sludge at San Antonio, Texas. Heisig and Brower (132) state that at Milwaukee the efficiency of purification is lowered by excessive amounts of oil and grease in the sewage. Wiest (107) at Lancaster, Pa., noted the same difficulty.

Paint Manufacture.—The discharge of certain wastes from the manufacture of paint into the sewage reaching the Calumet Works, Chicago, has slowed up the efficiency of the works (133). The manufacture of one type of organic dye was shifted to another locality because of the content of spent acid and other chemicals which interfered with bacterial action.

Packinghouse Waste.—The effect of packinghouse waste on the activated sludge works depends upon the dilution of the waste and its content of organic and suspended matter. At Fort Worth, Tex., preliminary treatment to remove settling suspended matter was required by the City before the sewage was received into the municipal sewers. The testing station of The Sanitary District of Chicago on the Stockyards waste and the operation of the Southwest Works all show that in certain dilutions the wastes yield readily to treatment. In as large a project as the Southwest Works, the increase in load is apparent on the days of active slaughter of animals, but to a less marked degree than at San Antonio, Tex., or Topeka, Kan. (85), where the packinghouse waste is less diluted by the sewage.

At Sioux Falls, S. D. (119), the municipal trickling filter plant became so overloaded, due to settled packinghouse waste, that provision was made for treating the wastes with ferric chloride, and an activated sludge unit was added for the treatment of the trickling filter unit.

Paper Wastes.—Sawyer (143) found satisfactory results could be obtained with sewage containing 6 per cent or less of Howard process (144) effluent and 10 per cent or less of raw calcium-base sulfite liquor.

Petroleum Products.—The effect of micro-organisms on petroleum and its products was studied by Stone, White, and Fenske (145) and Strawinski and Stone (146). Under certain conditions many petroleum products were broken down. Heukelekian and Schulhoff (147), however, found that many volatile solvents inhibited bacterial growth.

Textile Wastes.—Porges, Miles, and Baity (148, 149) indicate that the addition of sulfur dye wastes to activated sludge in amounts as low as 0.5 per cent by volume retards digestion. Digestion of sludge from sewage-dye waste mixtures is also inhibited, but not as markedly as by direct addition.

At Greensboro, N. C., Mengel (150) notes that when textile wastes were added, the reaeration of the return sludge became necessary, the air consumption increased, and the plant had to be enlarged about 50 per cent in the primary tank and digester. The amount of ferric chloride for conditioning was doubled, an operating unit costs increased 50 per cent.

At the Gastonia, N. C., activated sludge plant, Henderlite (151) overcame difficulties resulting from the discharge of textile dye wastes in the sanitary sewers by the addition of 300 to 360 pounds of ferric chloride (anhydrous) per m.g. of combined waste and sewage. Ferric chloride was added for 8 to 10 hours per day on five days a week, when the dye flow occurred. This reduced colors, increased removal of suspended solids and B.O.D., and eliminated bulking.

Wineries.—Hodgson and Johnston (152) find that at Glenelg, Australia, winery wastes in volume one per cent of sewage ran up the sludge index to 500 or 600 and broke down the process, with a profuse growth of filamentous organisms. No conventional control of the sewage treatment was found satisfactory.

Data from Activated Sludge Plants

The Committee has received operating data from a number of activated sludge plants. This material has been summarized in Tables XVIII to XXX, showing yearly averages for various determinations.

List of Tables

Performance of Sewage Treatment Works

Table No.	Works	Period Covered, Inclusive
XVIII	Calumet; Chicago, Ill.	1936 to 1940
XIX	North Side; Chicago, Ill.	1930 to 1940
XX	Easterly; Cleveland, Ohio	1938 to 1940
XXI	Indianapolis, Ind.	1930 to 1940
XXII	West; Milwaukee, Wis.	1930 to 1940
XXIII	East; Milwaukee, Wis.	1936 to 1940
XXIV	North Toronto, Ont.	1935 to 1940
XXV	Peoria, Ill.	1931 to 1940
XXVI	Rockville Center, L. I.	1935 to 1940
XXVII	San Antonio, Tex.	1932 to 1939
XXVIII	Springfield, Ill.	1930 to 1940
XXIX	Springfield, Ill.*	1930 to 1940
XXX	Wards Island, N. Y.	1938 to 1940

* This table shows average month, also maximum and minimum for certain determinations.

Table XVIII.—*Performance of Calumet Sewage Works, 1936–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M	Sludge Index	Raw Susp. Solids Per Ct. Vol.
		Susp., P.P.M.	B.O.D. P.P.M.	Susp., P.P.M.	B.O.D P.P.M.						
1936	62.7	176	97	23	16	0.41	4.7	21.0	2,700	38	58.7
1937	65.4	151	95	15	13	0.38	5.3	22.5	2,690	43	59.6
1938	61.8	133	83	13	14	0.36	5.2	24.7	2,230	52	59.9
1939	71.6	127	92	12	12	0.38	4.2	27.8	3,630	49	61.0
1940	67.2	121	107	12	10	0.42	4.6	29.7	3,830	59	63.0

Table XIX.—*Performance of North Side Sewage Works, 1930–1940*

Year	Flow Treated, M.G D	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index	Raw Susp., Solids, Per Ct. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.						
1930	139.4	109	84	16	8.5	0.52	5.3	24.3	3,800	—	68.0
1931	196.0	154	112	14	8.0	0.47	5.2	23.8	3,200	—	71.4
1932	200.3	137	117	12	9.7	0.44	4.9	24.8	2,800	—	68.1
1933	199.5	130	112	14	13.1	0.37	5.2	18.8	2,200	60[a]	71.3
1934	193.5	148	122	14	14.1	0.38	5.4	19.2	2,400	61[a]	71.2
1935	199.4	133	112	13	10.1	0.36	4.5	20.4	2,300	64	67.3
1936	204.6	137	108	14	8.5	0.36	4.3	21.6	2,400	67	67.1
1937	204.8	140	107	12	9.2	0.35	4.2	22.5	2,300	80	66.4
1938	200.1	142	110	10	8.6	0.35	5.1	22.4	2,300	73	64.2
1939	202.5	144	117	11	7.7	0.37	4.7	22.9	2,400	84	67.3
1940	188.2	144	129	11	7.0	0.40	5.5	22.4	2,400	85	67.1

[a] Based on 60 min. settling; all others on 30 min.

TABLE XX.—*Performance of Cleveland Easterly Sewage Works, 1938–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.					
1938	76.1	222	166	13.2	16.2	1.12	8.1	18.8		
1939	80.6	241	136	10.6	8.9	1.16	7.6	21.9	2,660	74
1940	89.1	238	130	12.4	10.9	0.92	6.9	25.0	2,804	63

TABLE XXI.—*Performance of Indianapolis Sewage Works, 1930–1940*

Year	Flow Treated, M.G.D.	Suspended, P.P.M.		B.O D., P.P.M.		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.
		Raw	To Aer.	Raw	To Aer.	Susp., P.P.M.	B.O.D., P.P.M.				
1930	18.8	319	228	262	230	29	20	1.03	8.26	34	2,100
1931	20.1	330	241	256	225	23	20	1.15	8.40	38	1,600
1932	24.6	318	195	251	222	30	24	0.92	8.89	36	1,300
1933		317	219	241	218	54	77				
1934	2.07	347	229	271	246	26	30	1.18	8.76	37	1,800
1935	2.15	365	223	251	219	25	29	1.23	8.28	43	1,600
1936	1.81	346	215	256	220	13	17	1.51	9.25	53	2,500
1937	25.31	323	215	215	191	14	17	1.25	10.46	27	2,600
1938	30.0	312	224	225	190	11	22	1.30	8.33	32	2,900
1939	21.1	371	258	263	233	8	19	1.51	8.75	44	2,900
1940	19.3	403	252	280	240	7	17	1.69	9.10	40	2,000

Note.—This record is for the Activated Sludge process only. Aer. means Aeration Tanks.

TABLE XXII.—*Performance of Original or West Sewage Works, Milwaukee Sewerage Commission, 1930–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.		Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Raw Susp. Solids, Per Ct. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.	Aeration Tank	Total				
1930				16	9.4						
1931				20	14.9						
1932				21	14.6						
1933	82.6	269	251	18	12.5	1.20	1.56	6.71	25.4	2,966	
1934	78.7	264	290	24	16.1	1.24	1.61	6.36	35.5	3,158	
1935	83.8	242	198	20	8.6	1.15	1.44	6.19	28.6	3,333	
1936	78.5	261	177	19	9.3	1.22	1.50	6.43	31.3	3,791	
1937	75.4	278	166	18	8.8	1.26	1.57	6.74	32.3	3,967	73.3
1938	76.9	256	160	16	6.8	1.21	1.53	7.05	26.4	3,833	75.5
1939	76.3	268	180	18	8.8	1.18	1.53	6.79	31.8	3,533	76.6
1940	76.2	290	256	18	12.9	1.19	1.85	7.01	27.2	3,558	75.2

TABLE XXIII.—*Performance of New or East Sewage Works, Milwaukee Sewerage Commission, 1936–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.		Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Raw Susp. Solids, PerCt. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.	A.T.	Total				
1936	38.7	261	177	17	7.8	1.22	1.63	13.52	22.6	3,658	
1937	40.8	278	166	14	6.6	1.21	1.70	12.37	29.3	4,075	73.3
1938	45.0	256	160	12	6.7	0.92	1.35	11.85	23.6	3,917	75.5
1939	45.1	268	180	14	8.0	0.81	1.17	11.57	25.6	3,633	76.6
1940	44.1	290	256	13.2	13.3	0.43	1.18	10.71	22.4	3,558	75.2

Note.—The East Plant went into operation on December 3, 1935. A.T. means Aeration Tank.

TABLE XXIV.—*Performance of North Toronto Sewage Works, 1935–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index	Raw Susp. Solids, Per Ct. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.						
1935	6.04	238	247	15	23	0.90	6.9	31	3,190	145	84.0
1936	6.59	238	246	8	14	0.96	7.14	23	2,740	130	83.6
1937	7.20	218	243	9	17	0.97	6.71	21	2,340	102	84.1
1938	6.72	262	255	9	15	1.02	7.16	19	2,410	85	81.0
1939	7.24	278	253	9	15	0.98	6.64	23	2,670	110	79.4
1940	7.68	280	290	7	15	0.92	6.4	30	2,910	129	—

TABLE XXV.—*Performance of Peoria Sewage Works, 1931–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index	Raw Susp. Solids, Per Ct. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.						
1931[a]	10.5	229	213	13	6.5	1.11	10.1	24.7	2,790		67.5
1932	9.9	210	190	15	12.9	0.98	9.6	25.3	2,620		74.4
1933	10.0	216	209	15	20.7	0.75	10.3	29.0	1,550		74.9
1934	9.4	262	254	16	20.0	0.79	11.3	28.7	1,020		79.7
1935	10.9	276	243	17	19.7	0.88	9.5	34.0	1,790		73.7
1936	12.7	305	246	18	17.6	1.17	6.3	34.6	1,400	157	79.4
1937	12.8	308	254	20	13.8	1.35	6.5	35.2	1,450	137	77.6
1938	13.6	307	214	28	15.9	0.98	6.2	35.3	1,510	200	77.1
1939	13.4	321	232	31	22.9	1.02	5.8	23.9	1,710	156	77.5
1940	12.3	357	273	32	28.6	1.00	5.2	40.7	1,820	158	75.8

[a] 5 months period.

TABLE XXVI.—*Performance of Rockville Center Sewage Works, 1935–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.					
1935	1.54	282	240	34	35	2.4	6.6	9	1217	80
1936	1.64	214	220	42	37	1.8	6.1	5	891	92
1937	1.99	319	249	37	35	1.8	5.1	5	733	118
1938	2.18	422	271	29	29	1.8	4.6	3	744	108
1939	2.12	478	279	33	35	1.9	4.8	5	745	68
1940	1.93	340	259	28	44	2.1	5.2	5	785	49

Note.—Effluent is for Activated Sludge treatment only, and does not show filter.

TABLE XXVII.—*Performance of San Antonio Sewage Works, 1932–1939*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.		Sludge Return, Per Ct.	Mixed Liquor, P.P.M.		Sludge Index
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.		Aeration Tank	Reaeration Tank		Aeration Tank	Reaeration Tank	
1932	16.12	342	225	35.5	16.2	0.93	7.55	1.01	51.50	2,700	6,100	
1933	15.66	359	214	12.6	12.9	0.97	7.72	1.03	52.10	2,800	5,900	
1934	15.88	314	208	14.4	18.9	0.97	7.68	1.03	51.10	2,600	5,400	113
1935	19.32	261	159	16.9	22.8	0.81	6.58	0.97	44.40	2,000	4,800	222
1936	18.33	269	162	89.8	47.4	0.93	6.78	0.95	47.70	1,700	3,800	389
1937	16.84	316	190	44	28	1.00	7.56	1.12	44.43	1,600	4,000	268
1938	17.25	320	190	22	26	1.02	7.78	1.29	37.3	1,400	4,300	243
1939	17.57	319	226	18	28	1.07	7.56	1.24	38.4	1,600	4,600	250

TABLE XXVIII.—*Performance of Springfield Sewage Works, 1930–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal.	Aeration Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index	Raw Susp. Solids, Per Ct. Vol.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.						
1930	2.7	186	166			1.21	5.3	22	4,181		62.4
1931	3.7	181	187	24	14	1.1	4.8	29	3,433		65.8
1932	7.6	162	168	21	17	0.91	5.0	20	3,013		63.
1933	6.7	155	152	13	13	0.83	5.3	24	2,186	119	66.5
1934	6.3	200	181	15	16	0.94	5.6	24	2,400	108	66.
1935	6.8	163	128	10	8	0.75	5.3	22	1,583	64	62.6
1936	6.3	223	188	10	16	0.85	6.1	20	1,390	99	66.4
1937	8.7	191	151	12	13	0.58	6.4	23	1,886	100	66.4
1938	7.6	180	159	12	14	0.75	6.6	28	1,362	171	64.4
1939	7.4	190	170	12	14	0.75	6.7	29	1,588	158	66.8
1940	6.9	199	203	10	13	0.84	7.0	30	1,840	157	69.4

Note.—Operation began on July 10, 1929. On October 1, 1931, additional aeration units were installed to provide capacity for entire flow.

TABLE XXIX.—*Performance of Springfield Sewage Works, Yearly Average and Maximum and Minimum Month, 1930–1940*

Year	Flow Treated, M.G.D.			B.O.D. Raw, P.P.M.			Air, Cu. Ft. per Gal.			Aeration Period, Hr.			Sludge Return, Per Ct.			Mixed Liquor, P.P.M.		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
1930				166			1.21			5.3			22			4,181		
1931	3.7	7.6	2.5	187	269	123	1.1	1.3	0.9	4.8	6.0	4.0	29	36	16	3,433	4,044	3,063
1932	7.6	10.2	5.3	168	217	100	0.91	1.22	0.63	5.0	6.6	3.9	20	29	15	3,013	4,151	1,660
1933	6.7	9.5	4.4	152	229	62	0.83	1.09	0.63	5.3	6.7	4.2	24	36	17	2,186	2,505	1,926
1934	6.3	7.8	4.8	181	274	112	0.94	1.06	0.75	5.6	6.2	4.8	24	38	20	2,400	3,036	1,897
1935	6.8	7.7	5.1	128	251	59	0.75	1.08	0.62	5.3	6.5	4.7	22	28	19	1,583	2,280	1,117
1936	6.3	8.1	5.3	188	242	140	0.85	1.08	0.66	6.1	8.7	4.8	20	27	15	1,390	2,450	780
1937	8.7	10.8	6.9	151	211	91	0.58	0.44	0.72	6.4	7.5	5.4	23	30	18	1,886	3,614	1,206
1938	7.6	10.5	4.9	159	221	70	0.75	1.09	0.40	6.6	8.0	5.5	28	43	19	1,362	2,331	1,043
1939	7.4	10.3	5.0	170	255	91	0.75	1.06	0.44	6.7	8.3	5.4	29	44	19	1,588	2,078	1,055
1940	6.9	8.9	5.8	203	237	146	0.84	1.18	0.54	7.0	7.8	6.1	30	40	20	1,840	2,564	1,168

TABLE XXX.—*Performance of Wards Island Sewage Works, 1938–1940*

Year	Flow Treated, M.G.D.	Raw		Effluent		Air, Cu. Ft. per Gal	Aeration, Period, Hr.	Sludge Return, Per Ct.	Mixed Liquor, P.P.M.	Sludge Index	Raw Susp., Solids, Per Ct.
		Susp., P.P.M.	B.O.D., P.P.M.	Susp., P.P.M.	B.O.D., P.P.M.						
1938	153	228	191	15	17	0.91[a]	5.6[a]	35	1,520	90	81.8[b]
1939	174	172	196	19	17	0.70	5.3	37	1,540	152	81.9
1940	192	220	207	14	12	0.65	4.6	45	1,900	128	80.6

[a] 9 months only; April to December. [b] 3 months only; October to December.

During a period of years, from 1930 to 1940, inclusive, these cover the results at the North Side (Chicago), Springfield, Ill., Indianapolis, Ind., and Milwaukee, Wis. (West or old plant). For shorter periods, data are given for the Calumet Works (Chicago), Milwaukee (East or new plant), San Antonio, Tex., Cleveland, Ohio (Easterly plant), Peoria, Ill., Wards Island (New York City), Rockville Center, L. I., and North Toronto, Ont. From an examination of these data, certain trends were noted.

Use of Air.—The use of air (Table XXXI) at various activated sludge plants illustrates a trend towards smaller amounts at Chicago, Springfield, and the new plant at Milwaukee. At San Antonio and Indianapolis, the trend is upward. The amount of air includes the air used in reaeration and in aerated auxiliary channels. The amount used at Milwaukee in auxiliary channels is larger than at many plants and is noted separately in Tables XXI and XXII. At Chicago, the air has been regulated to reduce the B.O.D. to a practicable degree but not to produce a large nitrate content in the final effluent.

Aeration Period.—The aeration periods at the various plants are assembled in Table III. The most marked reduction in the aeration

TABLE XXXI.—*Air Used at Various Activated Sludge Sewage Treatment Works, 1930–1940, Cubic Feet per Gallon of Sewage*

Year	Chicago		Milwaukee		Springfield, Ill.	San Antonio, Texas	Indianapolis, Ind.	Cleveland, Ohio	North Toronto, Ont.	Wards Island, N. Y.	Peoria, Ill.
	North Side	Calumet	West	East							
1930	0.52				1.21		1.03				
1931	0.47				1.1		1.15				1.11[b]
1932	0.44				0.91	0.93	0.92				0.98
1933	0.37		1.56		0.83	0.97					0.75
1934	0.38		1.61		0.94	0.97	1.18				0.79
1935	0.36		1.44		0.75	0.81	1.23		0.90		0.86
1936	0.36	0.41	1.50	1.63	0.85	0.93	1.51		0.96		1.17
1937	0.35	0.38	1.57	1.70	0.58	1.00	1.25		0.97		1.35
1938	0.35	0.36	1.53	1.35	0.75	1.02	1.30	1.12	1.02	0.91[a]	0.98
1939	0.37	0.38	1.53	1.17	0.75	1.07	1.51	1.16	0.98	0.70	1.02
1940	0.40	0.42	1.85	1.18	0.84	1.39	1.69	0.92	0.92	0.65	1.00

[a] 9 months period. [b] 5 months period.

period is at Peoria. At San Antonio, the plant is overloaded. At Indianapolis, the flow treated by the activated sludge process is limited. At Milwaukee, the West plant operates continuously on a fairly uniform load, whereas since 1935 the growth has been taken care of by the East plant, which is still underloaded.

Mixed Liquor.—The amount of suspended solids in the mixed liquor (Table VIII) shows a downward trend in the plants at the North Side (Chicago), Springfield, San Antonio and Peoria. The decrease is most marked at Springfield. The new Milwaukee plant shows a small downward trend, whereas at the old plant the suspended solids in the mixed liquor increased from 1933 to 1937 and then decreased somewhat. At Indianapolis, the trend since 1932 has been markedly upward, until the decrease in 1940. At the Calumet plant, Chicago, the trend from 1936 to 1938 was downward. At that time the solids in the mixed liquor were insufficient, so both the air and the mixed liquor solids were increased in the fall of 1938, with further increases in 1939 and 1940.

Nitrates.—A decided reduction in the nitrates is shown (Table IV) in the effluents of the plants at the North Side, Chicago, the new plant in Milwaukee, Springfield and Peoria. At San Antonio, there was a continuous reduction from 1932 to 1939, then a rise in 1940. At Indianapolis, the reduction occurred from 1936 to 1939. The Calumet plant, Chicago, shows an upward trend from 1937 to 1939, with a drop in 1940. The marked upward trend at Cleveland in 1938 and 1939 is followed by a drop in 1940. The Wards Island plant has maintained a low nitrate content of 0.5 to 0.57 p.p.m.

As no nuisance occurs in the absence of sludge banks if some dissolved oxygen is present in the diluting waters, there would seem little advantage in producing nitrates if dissolved oxygen is maintained consistently below the plant. High nitrates may be disadvantageous under such a condition, by stimulating the growth of algae or other organisms, which may die and cause a secondary nuisance.

For the smaller plants, where operation cannot be frequently checked, reasonable nitrate production may be a helpful safeguard. At Mogden, England, Lockett believes that nitrates must be present if dense sludges are required.

Ratio Return Solids to Incoming Solids.—The ratio of return solids to incoming solids has been discussed elsewhere. Most of the data were computed for five years only (Table IX). There is a downward trend at the North Side plant, in Chicago, from 1937 to 1940, inclusive, and a marked upward trend at the Calumet plant, Chicago, from 1936 to 1940, inclusive.

Sludge Index.—The wide variations in the sludge index (13) indicate the occurrence of difficulties connected with the operation of activated sludge plants. At San Antonio, Peoria and Springfield, the indexes are highest and show the widest variations. At the North Side and Calumet plants in Chicago, and at the Cleveland plant, the indexes are the lowest. At Rockville Center, there was a wide variation from 1935 to 1938 with better control in 1939 and 1940. The sludge index has increased in Chicago since 1935 at the North Side plant, and since 1936 at the Calumet plant. At the other plants listed in Table XIII the trend is indefinite, except at Rockville Center, where a marked drop occurred after a considerable rise.

Summary and Conclusions

The activated sludge process appears to be essentially bio-chemical, if carried out under aerobic conditions. Hence the first essential of operation is an adequate air supply.

Another principle of operation is to keep the oxygen demand of the mixed liquor as low as practicable. Consequently certain operators have advocated the dilution of very strong sewage with effluent, as at the Mogden plant near London, England.

At activated sludge plants, routine tests are commonly applied and correlated with plant performance. In general, the operators of the larger plants gage the performance by the determination, on samples collected frequently at critical points, of the 5-day B.O.D., suspended solids (both volatile and fixed), dissolved oxygen, and settling properties of the activated sludge. Organic nitrogen, ammonia, nitrites and nitrates are also determined. In some plants, microscopical examination of the sludge is a routine procedure, but in most only occasional. Where industrial wastes are a factor, other determinations, such as the pH and content of iron may be desirable.

Tests for dissolved oxygen in the mixed liquor indicate whether aerobic conditions are being maintained. From 0.5 to 2 p.p.m. are considered by various operators to be minimum permissible values, according to conditions, at the outlet end of the aeration tanks. In practice, up to 5 p.p.m. are found.

In reporting air consumption, the unit "cubic foot of air per gallon" of sewage is not directly comparable for different plants. A more suitable unit is suggested for comparative purposes, namely, the "cubic feet of air per pound of 5-day B.O.D. removed." The removal is computed from the analysis of influent and effluent of the activated sludge process, disregarding preliminary settling tanks or screens.

Sludge activity, measured in milligrams of oxygen required per gram of dry solids per hour, is a good index of operation. The optimum value may fall in a range between 5 and 10. The use of apparatus for quickly determining the rate of oxygen demand of activated sludge is not gaining favor, although the Bloodgood apparatus is used at five plants. Many operators agree with Enslow that the plant itself is its own best "odeeometer."

Sludge activity in the activated sludge plant is intimately related to the concentration of solids in the mixed liquor. This may be controlled by the amounts of sludge returned and of excess sludge wasted.

The ash content of the suspended solids of different sewages varies widely. It may be significant with reference to the sludge index, and in interpreting the results obtained in digesting or dewatering excess sludge. Plants operating with a sludge high in ash sometimes escape the bulking problems which come to the plants handling low ash sludge. Hence plants serving combined sewers may prove easier to control than those serving separate sewers.

Activated sludges high in ash usually require the use of less ferric chloride and produce a cake of lower moisture content and lower B.t.u. Such sludges also contain less organic nitrogen and have a lower fertilizer value per ton of heat-dried sludge.

The maintenance of an optimum content of solids in the mixed liquor is important. Within certain limits the lower content of solids should require less air for aeration. The optimum amount of solids in the mixed liquor at any given plant must be determined by experience. In general the present tendency seems to be toward lower values than formerly, now ranging from 1,000 to 2,000 parts per million. To determine the solids content many operators use a centrifuge, which gives quickly results sufficiently accurate for plant control. However, the aluminum dish (Smith) or bitumen Gooch crucible (Palmer) methods are more accurate.

The ratio of sludge return solids to the incoming sewage solids usually varies from 10:1 to 35:1, and in most cases falls between 10:1 and 25:1. Such ratios are based on total suspended solids. A study of sludge return may prove informative, based on the ratio of volatile solids in the return sludge to volatile solids in the incoming sewage.

The sludge index is desirably kept under 100, but is sometimes considered satisfactory if it is under 200, as at San Antonio and Wards Island.

The tendency for a number of years has been to avoid deep sludge blankets in final sedimentation tanks, and to favor the rapid return of the sludge to the aeration tanks.

Sludge conditioning in reaeration tanks appears of little value except in special cases.

Where excess activated sludge is to be digested, it is usually discharged to the primary sedimentation tanks. In some plants, sludge concentration tanks are provided, particularly where the excess activated sludge is to be dewatered on vacuum filters. Where excess activated sludge is digested, the return of supernatent liquor from the digestion tank to the raw sewage may be troublesome. In any case it is best to return the liquor at as uniform and low a rate as practicable.

The amount of air used per gallon of raw sewage has been decreased in many activated sludge plants to avoid unnecessary expense in producing nitrates.

Nitrates in the effluent may be detrimental as algae growths in the diluting waters may result. If there is always some dissolved oxygen in the receiving stream, nitrate production beyond 1 or 2 p.p.m. seems unwarranted for the larger plants, although for the smaller plants a higher content may be justified as a safeguard to operation.

Bulking is now regarded largely as due to sudden increase of organic load or under-aeration. *Sphaerotilus* is considered by some as a symptom of bulking rather than the cause.

The dissolved oxygen in the effluent from final settling tanks is often too low. Some quick reaeration of the effluent is desirable by suitable agitation, by cascades or other means. How much of this entrained and dissolved oxygen satisfies B.O.D. is still subject to determination.

Considerable data are accumulating to indicate that porous diffuser plates clog within several years after installation. Under favorable conditions they have been in service for over ten years with practically no attention. Under unfavorable conditions, such as the presence of a large amount of spent acid, pickling liquors from the iron and steel industry, serious clogging has occurred in 5 to 18 months. Under certain conditions, they have been cleaned in place by introducing gasoline or chlorine into the air lines. Under other conditions, acid treatment and wire brushing or spalling by a blow torch may be required.

The iron contents of sewages treated at some seventeen activated sludge plants have varied from 1.6 to 17 p.p.m. Fe. Apparently plants receiving sewage low in iron have had little trouble from diffuser plate clogging, whereas high concentrations, particularly in "shots" of pickling liquor, have aggravated plate clogging.

Certain industrial wastes apparently are specifically detrimental to activated sludge treatment, in particular, spent acid pickling liquor and wastes from the manufacture of paint or other material, which may inhibit bacterial action or promote clogging of diffusers.

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OPERATING EXPERIENCES IN NEW YORK CITY *

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The subject of this paper is a broad one. When I considered this topic it seemed to me that it would be a simple matter to find plenty of interesting material among the thirteen old and new sewage treatment plants that are operated by the City. The real problem I find, however, is one of selection in order to keep the presentation within bounds of time and to present the type of material that will prove most interesting.

The tools that are available for use in our field here are not different than are common elsewhere. Their selection and adaptation are often controlled by particular conditions that face us. There are perhaps two general situations here that in a large measure control the type of works we build and operate in New York.

The first and major consideration is that our works have no splendid isolation. They must be built in congested areas close to residences and large groups of people. The type of works built therefore must have its operations so controlled that no odors result and that the operations are not unsightly or otherwise offensive. Because of the popular conception of a sewage treatment works and the bad reputation that some works have had in the past, our task of overcoming objections to the building of new works in particular locations is not a simple one. We have to sell the idea of the works as well as engineer them. The second controlling consideration is that most of our major plants are accessible to tidewater which means that we have available a cheap and efficient method of disposing of our solids at sea.

Primarily, for these reasons and for others correlated with them, the tendency has been to go in for sludge digestion, with the side line of gas utilization and power production; the disposal at sea of solids not wanted for fertilizer; the adoption of seasonal treatment in some places and, in general, the search for efficient short-time treatment that can largely be operated with the power we produce. In the following pages I shall try to outline our experience with the devices used to accomplish those ends.

Disposal of Solids

The ultimate disposal of solids removed from sewage is the tail that wags the dog as far as most treatment plants are concerned and it may be well to start with that end first.

Sea Disposal of Solids.—By far the greatest part of our sludge goes to sea, the bulk of it being a mixture of raw and activated sludge from Wards Island. This operation is quite successful. Last year the three

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1500-ton Diesel operated vessels disposed of sewage solids at a cost for direct operation and maintenance of $1.88 per m.g. of sewage treated or $2.40 per ton of dry solids, and this included rather heavy charges for collision damage which we hope are unusual. At the dumping area, 11 miles from land, no offense is created as the sludge disappears quickly and little of the material can be discovered ½ mile from the point of dumping.

The real problem in the handling of raw sludge is in the control of odors. The sludge storage tanks on Wards Island hold about 188,000 cubic feet and at times the odor above them in the enclosing building is terrific. These gases are drawn at the rate of 15,000 c.f.m. through activated carbon filters and given an application of about 40 to 60 grams of ozone per hour. This is the only installation of this type that I know of in a sewage plant. It has resulted in an adequate control of odors. At times when the filters have not been working, reasonable results have been secured with ozone alone. We have no good quantitative method of measuring the odor removal or the proportion of work done by the activated carbon and ozone. The filters alone may remove from 80 to 90 per cent of the odors, judged by general impressions of different observers. Their effectiveness, of course, depends on the effective capacity remaining in the activated carbon.

Some difficulty has been experienced in maintaining the effectiveness of the activated carbon canisters on the gas vents of the sludge vessels because of their smaller capacity and the high moisture and odor content of the gases when loading. Frequent replacements are necessary. The life of the canisters and carbon is short so that the operation is troublesome and not inexpensive. Larger and improved devices are about to be installed on one of the vessels and also on the shore installation. We are trying to learn more about odor adsorption, including spray scrubbers and new types of containers for activated carbon.

Sludge Digestion.—There are a number of reasons why sludge digestion has been quite generally adopted. The economics of sea disposal depend on large individual shipments. In our smaller plants the storage of raw sludge between trips would result in considerable offense because of the length of time necessary to accumulate a shipload. Some locations are subject to ice closure in winter, making safe and inoffensive storage desirable. Another consideration is the reduction of sludge volumes that results from digestion. The recovery and utilization of digester gases furnish a source of power and heat that makes possible a substantial reduction in operating charges against the tax levy budget.

There are three digester installations now being operated. That at Coney Island has been operating over five years, at Tallmans Island the digesters have been in service over two years and at Bowery Bay only a few months.

At Coney Island there are eight digesters, each provided with a gasometer type of cover providing storage of gas to the extent of 45 per cent of the digestion capacity. This type of cover is also used at

Bowery Bay and installed at Jamaica. The tanks receive sludge resulting from chemical precipitation during the summer and plain sedimentation during the winter. The only source of power at this plant is the gas-engine operated generators. For the past three years it has been necessary to purchase only about 0.85 per cent of the total gas used to operate the engines and furnish heat to the buildings.

Up to this spring the loadings on the digesters have been low, averaging in the past two years about 1.5 pounds of solids per month per cubic foot of tank capacity with a minimum monthly figure of .9 lb. and a maximum of 2.33 lb. Last year solids went to the tanks at 7.9 per cent solids with 65 per cent volatile matter and came out as digested sludge at 7.1 per cent solids with 47 per cent volatile. The reduction in volatile solids was 60 per cent.

Late this spring the flow coming to the plant was more than doubled and the solids load trebled. The six new digesters of the enlarged plant are not yet finished and this increased load has been handled by the old digesters. Prior to this time the temperature in the old digesters had been slowly raised from 82° F. to 95° F. For the first 13 days this load amounted to 6.6 pounds per month per cu. ft. of tank capacity and for the next two months 5.0 pounds. About the only adverse effect noted was that the volatile in the digested sludge increased from about 45 to 50 per cent and solids in the decanted liquor increased to such an extent that the practice of decanting was minimized. We were at first uncertain as to the ability of the digesters to carry this heavy load, as it was known that at one time there had been a heavy scum layer in the tanks as well as substantial deposits of sand which cut down their effective capacity. In view of the loads actually carried it seems probable that the greater activity and higher gas production per unit of tank area must have resulted in a reduction of the scum layer.

All the digested sludge produced at Coney Island is barged to the nearby Marine Park which is as yet undeveloped as a park. Here it is pumped ashore to shallow lagoons on a sandy area. When dried the material is removed by the Park Department for use throughout the City on parks and parkways.

The digester installation at Tallmans Island differs from the Coney Island plant chiefly in that the covers here are of the Downes type, floating on the sludge with no gas storage. The sludge treated is a mixture of primary and excess activated sludge. On a dry basis 70 per cent is primary and 30 per cent secondary sludge. The sludge is unique in the heavy concentrations that have been secured. During 1940 sludge going to the tanks has had a concentration of 6.3 per cent solids with 58.5 per cent volatile and been removed at 9.6 per cent with 33 per cent volatile. Tank loadings and general effects of digestion have closely paralleled the Coney Island experience.

In summer, when no extra gas is required for heating, gas production is substantially equal to the power requirements of the main sewage pumps and air blowers. For three months this year, where we have had a metered record of waste gas, the average production has been 105 per cent of the requirements. Actually about 1.5 per cent has been purchased from the utility company during the same three-month period.

At both Coney Island and Tallmans Island it has been found advisable to pass liquor decanted from the digesters through two digesters set aside for this purpose before returning it to the head of the plant. The solids going to these two digesters are fairly heavy so that the separated tanks are still effective parts of the digestion system. When tank loadings are moderate this results in a fairly clear decant liquor from the secondary digesters.

Screening and Grit Removal.—The removal and disposal of the coarse materials received at the head of a treatment plant is one of the major ''headaches'' of sewage treatment. This is particularly true if this plant serves a combined system of sewers. The incoming material is by no means evenly distributed but rather comes in in huge quantities at times of storms and the amount varies greatly among different drainage areas.

Generally speaking, our major plants are provided with coarse racks with about 3-inch openings followed by bar screens of about 1-inch openings. In our first layouts the coarse racks were manually cleaned. In the Wards Island grit chambers this manual work was so difficult and back breaking that mechanical rakes have been installed and are now in operation. These rakes were made from designs worked up in the Department modifying the Laughlin under-raking type and bid fair to meet the difficult requirements of this work. In the newer larger plants, mechanical appliances are called for in this service. Our 1-inch screens are all mechanically cleaned. They include several types, all of which function reasonably well.

As much of the screenings as is practicable are ground and re-introduced into the sewage. The very coarse material and large surpluses during storms are removed in cans or in bulk and disposed of in the city incinerators.

In our grit removal devices we are experiencing a gradual but important improvement. Some of the earlier so-called grit washers turned out material that could be safely disposed of only by incinerators. In others, the output is entirely inoffensive with only about 4 per cent organic material. Excessive wear and replacements are common both to the older types of washers as well as some of the newer ones. This is inherent perhaps in the gritty material. Our whole experience with screening and grit handling is a confirmation of the general practice in having an adequate duplication of units and where possible having more than one way of carrying out an operation. The traveling cranes with their attached buckets on the Wards Island system have many times proved to be a life saver in the handling of excessive loads of screenings and grit and during temporary failure of other devices.

Interesting and novel methods have been developed for the disposal of fine screenings from the Jamaica and Hammels plants treating a flow of about 40 m.g.d. The fine screenings are passed through a centrifuge located at Jamaica, coming out as a cake containing about 65 per cent moisture. This cake is then converted into an inoffensive and useful fertilizer by composting methods developed by Dr. H. W. Charlton after many months of experimentation. The methods are quite simple. About 2 per cent of gypsum by weight and 2 per cent of straw by volume are added to the cake as it leaves the centrifuge. The mixture is then piled on the ground where the composting temperature of around 150° F. develops rapidly. After a month or so the material is ready for use. It then is chocolate brown in color, entirely devoid of offensive odor, loose in texture and resembles a high grade natural humus or peat moss. It contains about 80 per cent organic matter, 2.5 per cent nitrogen and about 1 per cent phosphoric acid. Last year 1600 tons of screenings were thus treated and all used by the Park Department as a mulch around trees and shrubs in the city parks.

Treatment Processes

Primary Tanks.—Of all our treatment devices the primary settling tank is by far the simplest and most efficient in work performed within its limitations. The several types we operate are effective and produce sludge of satisfactory concentration. Our settling results with longitudinal flow tanks have been relatively better than with center inlet and radial flows.

Activated Sludge.—At many of our locations the concentration of pollution is such as to require treatment beyond that secured by primary treatment alone. In those cases, where year round treatment is desirable, the activated sludge process has so far been found to be the most economical form of treatment. The unit cost of B.O.D. removal is less in an activated sludge plant than in a simple sedimentation plant when it is considered that in all cases sewage must be pumped. This is particularly true in those modifications of the process where aeration periods are short and power requirements can be substantially met from by-product power. The high bacterial removal of this process is of importance.

The activated sludge process is often thought to be a temperamental one. The facts are, however, that month-in and month-out consistent removals of from 90 to 95 per cent in B.O.D. and suspended solids are secured. It is true that at times and for extended periods solids become light and settle slowly, to low concentrations, and the operators must adjust air volumes, vary solids concentrations and otherwise control conditions to the best of their abilities.

I think few of us realize the sudden variation in load that activated sludge must meet and accommodate itself. It is common at Wards Island, for example, for the B.O.D. load to jump from 1,000 lb. per hour at 8 A.M. to 8,000 lb. per hour at noon. How much of this is in a form to be quickly assimilated by the sludge and how much is more slowly available, we don't know. All we do know is its 5-day demand. There are some indications from biometer readings that oxygen demands may at times exceed our ability to dissolve oxygen into the sewage by means of the ordinary aeration systems.

Activated sludge is our most important secondary process. Our experiences with it are chiefly at the Wards Island plant, the Tallmans Island plant, with its provisions for "step aeration," and an experimental pilot plant on Wards Island. The Wards Island plant has a rated design capacity of 180 m.g.d., but in July of this year the average flow was 217 m.g.d. The portion of the Tallmans Island plant now in use was rated at 20 m.g.d. but the July flow here was only 14 m.g.d. The B.O.D. removal per cubic foot of aeration tank capacity at Wards Island is nearly three times that at Tallmans Island. The sewage at Tallmans Island is more amenable to sedimentation and higher percentages of organic matter are removed in the primary tanks. The volatile solids are higher at Wards Island than at Tallmans Island. It is thus seen that one plant is heavily loaded and the other is on the light side. On the other hand, serious trouble has been encountered at Tallmans Island at times due to heavy discharges of oil and dye wastes.

Because of the many points of divergence in the two plants, direct comparisons are difficult. The final results at both locations are satisfactory. The average results during 1940 are as follows:

1940 Results

	Wards Island	Tallmans Island
Suspended Solids		
Raw	220 p.p.m.	151 p.p.m.
Final	14 p.p.m.	14 p.p.m.
Per cent removal	94	91
B.O.D.		
Raw	207 p.p.m.	126 p.p.m.
Final	12 p.p.m.	16 p.p.m.
Per cent removal	94	87
Total bacteria 37° C. agar—per cent removal	98	99.2
Coli-Aerogenes—per cent removal	99	99.8
Concentration of solids removed	4.0	6.3

The general physical conditions are as follows:

	Wards Island	Tallmans Island
Sewage flow—m.g.d.	193	14.3
Aeration period (conventional aeration)	4.6 hrs.	3.6 hrs.
Air consumption—cubic feet per gal.	.65	.49
Solids concentration in aeration tanks	1900 p.p.m.	1500 p.p.m.
Final settling tank flow—gals per sq. ft. per day	800	660
Per cent return sludge	44	55
Sludge index (Donaldson)	.78	1.3

Perhaps the most interesting point of difference in the two plants is that much greater flexibility in operation is possible in the provisions that are made at Tallmans Island for "step aeration." Under this system sludge is returned from the final tanks to the head end of the aeration tanks. Here it may be joined by the entire flow of settled sewage as in the conventional system or this settled sewage may be added to the returned sludge at two additional points along its flow through the tanks. The amounts added in each of the three steps can be varied or entirely eliminated as desired.

In making provision for this control it was recognized that two distinct and separate things took place in an aeration tank. First, there is a contact phenomenon in which the suspended and colloidal matter in sewage is adsorbed on the activated sludge floc. If the sludge is in good condition this is accomplished quickly. Probably this action is mostly completed within 30 minutes. The second action is the biological assimilation of the material adsorbed on the floc and the regeneration of this floc. This action goes on for several days as the sludge is recirculated within the plant. The dilution of activated sludge with sewage at successive points in its flow through the tank accomplishes several things. It gives the sludge a longer contact period in the tank than it otherwise would have, it permits the storage of more sludge in the tank for the same effluent concentration and therefore increases the time available for its conditioning. The first contact with sewage and sludge results in great biological activity and consequently high demand for oxygen which lessens rapidly as the more readily assimilative substances are used up. The procedure under "step aeration" decreases the high biological shock on initial contact with sewage by reducing the amount of the "charge," and supplies food to the sludge more uniformly, that is, at more frequent periods. It was hoped and still expected that higher tank loadings can thus be secured with substantially equivalent results.

At Tallmans Island, as a result of two years' experience with the system, it has been found best to use both conventional and "step" aeration as conditions dictate. Robert Shapiro, the chemist there, gives some of these controlling conditions as follows:

"Step Aeration" is used (the number of steps used being dependent on the intensity of the conditions):

1. When there is persistent increase in volatile content of the activated sludge—indicating the need for more oxidation of adsorbed organics.
2. When the sludge index is decreasing steadily or D.O.'s dropping steadily—which indicates the need for increased sludge aeration period as the sludge is probably overloaded.
3. In case of high *sphaerotilus* growths—which is taken as an index of overloading or poor sludge condition.

Conventional Aeration is used:

1. When primary effluent solids are low or flow is low—conventional aeration permits carrying less solids in the aerator, but with the same end concentration, avoiding undernourished activated sludge.
2. When there is over-aeration—as indicated by high D.O.'s and a pinpoint floc in the final effluent that does not settle readily.

The operators at Tallmans Island feel that "step aeration" provides them with a valuable method of control but I am not yet satisfied that we know the limitations or full possibilities of this method. Since February of this year an experimental plant has been operated on Wards Island under the immediate supervision of Dr. Setter where parallel experiments are being run on the conventional and "step" aeration systems. The plant operates on the effluent of the Wards Island primary tanks and has a combined capacity of 20 g.p.m. Experiments run so far have been designed to compare the two processes at successively increased rates of flow up to the limit of the process, while maintaining an aeration liquor effluent solids concentration of 1,000 to 1,500 p.p.m. Preliminary results indicate that for aeration periods of about 6 hours, "conventional aeration" was equal to or better than "step aeration." For sewage loadings to produce about 3 hours aeration, "conventional aeration" had reached a safe limit and was inferior to "step aeration." The sewage load was increased in the "step aeration" process to produce a theoretical detention period of 1½ hours. After a short "breaking in" period, satisfactory removals (the effluent B.O.D. rarely exceed 20 p.p.m.) were obtained during four successive weeks of operation. It is still too early to draw positive conclusions but such results as have been secured tend to bear out the early expectations of the process.

Final Settling Tanks.—The more I see of final settling tanks the more firmly am I convinced that the final settling tank is a vital part of the aeration system of an activated sludge plant. The action in the aeration tank cannot properly be analyzed without at the same time taking into account what happens in the final settling tank. Unfortunately, I know of few final tanks that in my opinion are correctly designed for their purpose. Certainly, the two examples at Wards Island and Tallmans Island fall short of the ideal. It is hoped that the new tanks that will be placed in operation at Bowery Bay in the near future will be a step in the right direction.

The conditions that exist in the final tanks at Wards Island in all probability are typical of those in many other plants and there is no reason to believe that similar conditions do not exist in circular tanks. At Wards Island, the tanks are rectangular, 43 ft. wide and 179 ft. long, cleaned by conveyor mechanisms that collect sludge to a central sump distant about 90 feet from the two ends of the tank. The influent is distributed across the center of the tank at the surface, the effluent being over weirs near the far ends of the tank. The withdrawal of return sludge is directly below the influent. This results in a vertical current that tends to induce horizontal velocities in the tank, with currents along the bottom toward the effluent end and returning to the influent end along the top. This action is probably increased by the flow of the sludge along the tank bottom because its specific gravity is higher than that of the liquid.

The magnitude of these currents was measured in a cooperative test with engineers from the Sanitary District of Chicago. At the time of this test there was a level static layer of sludge on the bottom of the tank to a depth of about 2 feet. Above this there was a zone about 4 ft. deep moving toward the effluent end with velocities immediately above the sludge zone up to 6 to 7 ft. per minute. Above this zone currents return toward the influent end with velocities ranging up to a maximum of 4 to 6 ft. per minute. The serious condition here is that the flow of sludge along the tank bottom is counter to the drag of the collector mechanism. This mechanism moves at only one foot per minute and has nearly 90 ft. to travel. Its flights are only 8 in. deep working at the time of the test in a blanket of 2-ft. depth so that it is clearly evident that much of the sludge must remain in the tanks for a period of many hours. This cannot help but have an adverse effect on sludge condition and place an undue load on the aeration facilities.

In an effort to correct this condition, the new tanks at Bowery Bay provide for the taking off of return sludge at the effluent end. The collector mechanism moves toward the effluent end which is the same direction as the natural flow of the sludge along the tank bottom. The flights are given a speed of up to 3 ft. per minute, the blades being feathered on the return course to minimize eddy currents under these higher speeds.

Chemical Treatment.—Chemical treatment, on a seasonal basis, has been practiced at the Coney Island plant since 1936. Coagulation with iron salts is ordinarily in effect from the middle of June to the middle of September with complete sterilization by means of chlorination during this same period. Partial chlorination, largely for odor control, is carried on a few weeks before and after the period of iron treatment. Coagulation with chemicals is carried only to the end point of securing an effluent turbidity of about 50 p.p.m.

During 1936 only temporary chemical dosing apparatus was available and ferrisul was used as the coagulant. In 1937 the airveyor system and regular chemical dosing equipment was in use and a variety of chemicals were tried out. These included chlorinated copperas, chlorinated copperas and lime and ferric sulfate both with and without lime. In 1938, 1939 and 1940 chlorinated copperas was used based on the overall picture of cost and greater ease and convenience of handling. It had been found to be impracticable to use the airveyor system with two chemicals such as lime and iron salts because of binding in gates and equipment due to chemical reactions between remaining vestiges of lime and iron. This year a favorable price on ferric sulfate resulted in the use again of this chemical. Unfortunately, further binding of the airveyor equipment resulted and it became necessary to fill the daily supply hoppers by hand.

The general results for typical periods when coagulating chemicals were used and the results with plain sedimentation are shown in the following table. The settling tanks at Coney Island are 14 ft. deep and have a theoretical detention period of 2 hours at 35 m.g.d. with a period in the flocculating tank of about 11 minutes.

Operating Results of Coney Island Sewage Treatment Works

	1937		1938		1939		1940		1941	
	Chemical Precipitation	Plain Sedimentation	Chemical Precipitation	Plain Sedimentation	Chemical Precipitation	Plain Sedimentation	Chemical Precipitation	Plain Sedimentation	Chemical Precipitation	Plain Sedimentation
Average flow, m.g.d.	22.4	18.0	23.0	18.8	22.8	20.5	21.8	20.0	43.6	20.0
Susp. solids in raw sewage, p.p.m.	172	140	209	165	201	172	168	161	218	175
Susp. solids in effluent, p.p.m.	47	83	47	76	36	73	38	79	60	81
Per cent susp. solids reduction	73	41	77	54	82	58	77	51	73	53
B.O.D. in raw sewage, p.p.m.	109	120	123	122	147	130	140	137	136	139
B.O.D. in effluent p.p.m.	49	87	52	87	46	85	54	100	70	107
Per cent B.O.D. reduction	55	28	58	29	69	35	61	27	49	23
Coagulants used	Ferrisul chlor.-copp. Lime	—	Chlor.-copp.	—	Chlor.-copp.	—	Chlor.-copp.	—	Ferrisul	—
Coagulant dose, lb. per m.g.	†	—	261‡	—	251‡	—	223‡	—	228	—
Cost of coagulants per m.g.	$4.21	—	$2.26	—	$2.23	—	$2.07	—	$2.77	—
Cost of chlor. per m.g. for disinfection	$3.02	—	$2.66	—	$2.89	—	$3.13	—	$3.54	—
Total cost of chemicals per m.g.	$7.23	—	$4.92	—	$5.12	—	$5.20	—	$6.31*	—

* To September 14, 1941.

† Experimental use of combinations of coagulants during 1937.

‡ This weight represents that of copperas plus a theoretical amount of chlorine.

This discussion of our operating experience has been chiefly an evaluation of present devices with indications of possible improvements that can be incorporated in our newer designs. Under the pressure of an active building program, time is often lacking to get the complete story on operating devices before the next design is crystallized and under contract. We are attempting to pick up the loose ends as we find them and hope that improvements in new works will be progressive. So far, in the new plants that have been built, we have been successful in attaining the results desired. This has been done without the creation of offensive conditions or impairment to neighborhoods near the plants.

There are many interesting and sometimes difficult operating problems and experiences that are important, but their consideration would have extended this paper to undue limits. Not the least of these subjects would be securing of funds for construction and proper operation and maintenance, the securing and properly caring for the required personnel, and the general administrative control in a large city. I should also like to have thrown a few bouquets to the men who are making our plants work, often under adverse conditions, but I know you all realize that not much can be done without a loyal and interested personnel. Suffice it to say that our operating efficiencies are either improving or are at a high level and our operating costs are going down. That this condition will continue, I have every reason to expect.

DIFFUSER PLATE CLEANING VERSUS COMPRESSED AIR COST *

PART I. PERMEABILITY TESTING AND DIFFUSER PLATE CLEANING

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The standard of comparison or rating of diffuser plates is permeability, defined (1) as the number of cubic feet per minute of air at 70° F. and 10 to 25 per cent relative humidity, which will pass through one square foot of diffuser area to the atmosphere, under a differential pressure equivalent to two inches of water below the plate when it is tested dry in a room maintained at a temperature of 70° F. and a relative humidity between 30 and 50 per cent. A precise determination of this value requires elaborate control of conditions and equipment. However, a simple procedure has been found satisfactory for comparative purposes in testing plates at the Cleveland Easterly Sewage Treatment Plant.

An apparatus for permeability measurement was constructed after the type described by Beck (2). It consists merely of a metal box for tightly holding the plate to be tested, an orifice meter for measurement of rate of flow of air to and through the plate, and a draft manometer for measurement of pressure under the plate.

The orifice meter, a ¾-in. thin plate orifice in a 6-in. pipe, was calibrated using a dry gas meter. At a flow rate of 47.5 cu. ft. per minute the orifice differential was 36 in. water with a loss through the meter of ⅝ in. of water. No air temperature, pressure or humidity determinations were made at the time of calibration.

In testing the plates to obtain a permeability value, the following procedure was followed. The plate was thoroughly dried and placed near the heating plant. After cooling to room temperature, the plate was clamped to the test box using the standard rubber gasket of the Burger-type plate holder to obtain an air-tight seal. The air supply (filtered air as used in sewage aeration) was then regulated to give 2 in. water pressure under the plate, and the pressure differential through the orifice was read. If the absolute permeability was to be derived, diffuser air temperature and humidity and barometric pressure recordings were required. From the orifice meter calibration curve, the rate of flow of air through the plate in cu. ft. per minute was determined corresponding to the orifice differential pressure.

* Joint Paper Presented at Ohio Conference on Sewage Treatment, Mansfield, Ohio, September 18–19, 1941.

The resulting value in cu. ft. of air per minute was not absolute permeability, for a number of reasons. No control was made in temperature and humidity of the test air nor of the room air. In addition to the exposure of the one sq. ft. top area of the plate, the four sides were also exposed, thus resulting in a possible exposure of more than one sq. ft.

Beck (2) demonstrated that the effect is negligible of a change in barometric pressure, or of relative humidity of the test air or room air up to 71 per cent. The temperature of the plate, however, does influence the permeability; for example, a plate rated 40.0 at 70° F. has an apparent permeability of 42.3 at 40° F. (1). Such a variation, however, is still within the usual tolerance in specifications, namely, ± 10 per cent of the mean rating of the plates.

Preliminary Tests

A number of unused diffuser plates were tested for the purpose of checking the permeability apparatus.

Test 1.—An unused plate with a rated permeability of 38.0 was sealed so that a 10-in. square area of the plate was available for passage of air. This was accomplished by painting, with a heavy paint, the sides of the plate and a margin around the top and bottom surfaces. Before and after sealing, the air rate determinations were made on the plate, using a standard rubber gasket to seal the plate. The test data are given in Table I.

Table I.—*Rated versus Calculated Permeability*

Area Exposed	Plate Pressure, Inches Water	Plate Temp., Deg. F.	Air Passage, Average Cu. Ft. per Min.
Full area	2	47	39.5
100 sq. in.	2	45	26.4

The results indicate that an area approximately equivalent to one square foot was available for air passage since the permeability calculated from the rate per 100 sq. in. checks with the rated permeability.

Permeabilities

Rated Permeability: 38.0 cu. ft./min./sq. ft. at 70° F.
Test Permeability: 39.5 cu. ft./min./exposed area at 47° F.
Partial Permeability: 26.4 cu. ft./min./100 sq. in. at 45° F.
Calculated Permeability: 38.0 cu. ft./min./sq. ft. at 45° F.

Correcting the permeability to 70° F., using an increase in apparent permeability of 0.76 cu. ft. for a decrease in plate temperature of 10° F. (1), the permeability values check reasonably closely those indicated in Table II.

TABLE II.—*Corrected Permeabilities, 70° F.*

Permeability	Cu. Ft. per Min. per Sq. Ft.
Rated:	38.0
Test:	37.8*
Calculated:	36.1

* On exposed area.

Test 2.—A number of unused plates were tested to confirm the reliability of the apparatus. The results are presented in Table III. The corrected permeabilities are the test permeabilities converted to 70° F. using the factor 0.76 cu. ft. per 10° F. The agreement is close, the average test and corrected permeabilities being within 0.4 and 1.1 cu. ft. of the average rated permeability, or within 1.0 and 2.8 per cent, respectively.

TABLE III.—*Permeability of Unused Plates*

Test Permeabilities			Plate Temp. Deg. F.	Permeabilities	
Top	Bottom	Ave.		Corrected	Rated
36.2	38.0	37.1	50	35.6	36.0
37.1	36.9	37.0	50	35.5	37.5
40.0	40.8	40.4	50	38.9	39.0
35.0	37.0	36.0	51	34.5	36.0
37.2	37.3	37.2	50	35.7	37.5
40.0	40.2	40.1	50	38.6	39.0
40.4	40.7	40.6	51	39.2	41.0
41.5	41.0	41.3	52	40.0	42.5
44.3	44.5	44.4	52	43.0	43.0
45.0	44.8	44.9	52	43.6	44.0
44.8	45.3	45.0	49	43.4	44.0
41.8	41.2	41.5	49	39.9	39.9
35.3	36.5	35.9	49	34.3	36.1
Average................		40.1		38.6	39.7

The results of these tests demonstrated that permeability ratings made in the rather unorthodox manner described compare favorably in accuracy with the ratings supplied by the manufacturers. Hence the procedure can be satisfactorily applied to plant studies and tests.

PLATE CLEANING

Twenty-gallon crocks were provided for treating the plates, with a rectangular wooden tank with water connections for washing and several wooden racks for draining. The washing tank was constructed of cypress with the seams tongue-and-grooved and white-leaded, heavily painted with bituminous paint. Supports made of ⅜-inch rod covered with rubber tubing were hung in several of the crocks to hold the plates while the acid drained out, after soaking and prior to washing. Acids were handled with synthetic rubber gloves.

The materials selected for test cleaning were 36° Baumé nitric acid, 18° Baumé muriatic acid, 66° Baumé sulfuric acid, caustic soda, dichromate of soda, and gasoline. The nitric and muriatic acid were used as such, the muriatic acid also in a one-to-one solution. The sulfuric acid was converted to sulfuric-chromic acid solutions containing 2 and 5 per cent dichromate of soda. The 2 per cent solution was made by adding the pulverized dichromate to the acid and dissolving with stirring. The 5 per cent solution required solution of the dichromate in a minimum of water and the addition of acid. After a period of stirring, the precipitated dichromate re-dissolved. The caustic soda was used as a 20 per cent solution.

The method of cleaning consisted in soaking the plates for several hours in the cleaning agent, followed by a period for allowing the cleaning agent to drain out of the plate, and finally a thorough rinsing in water. It was soon discovered that in order to remove all of the cleaning agent held by the plate, special effort was required in washing. Mere standing in the tank of running water for even a long period did not satisfactorily produce good rinsing because of the fine porosity of the plates. The acid and clogging material remaining after draining necessitated a more vigorous process of expelling. This was accomplished by the repeated process of rinsing in water, in which the plates were removed from the water between rinsing and allowed to drain for 10 to 15 minutes. The same result was obtained by filling and drawing the rinsing tank. As many as six washings or more might be required. The washing process thoroughly flushed out all the dissolved and loosened material which would otherwise remain to clog the plate on drying, and assured successful cleaning.

The same procedure was tested in cleaning clogged plates. These plates had been in service for about a year at the Cleveland Easterly Plant. The Easterly sewage is moderately strong with a normal iron and grease content.

The plates were treated with the several cleaning agents and combinations of them. Approximate permeability readings were taken, as described, readings being made with each side exposed and the average taken as the test permeability. The rated permeability was that stamped on the plate by the manufacturer.

Test 1. Muriatic Acid—Gasoline.—Two plates were soaked one hour in muriatic acid, washed, dried, and tested. Following this the same plates were washed in gasoline, and retested.

Data:

Test Permeabilities—Air 58° F.

	Rated Perm.	Clogged	Mur. Acid	Incr.	Gasoline	Incr.
Average.......	37.6	10.7	13.8	3.1	13.5	−0.3

Results.—Muriatic acid produced only a minor cleaning effect. Secondary washing in gasoline had no cleaning effect.

Test 2. Gasoline—Muriatic Acid.—Two plates were soaked in gasoline, dried, tested, then followed by treatment in muriatic acid for one hour.

Data:

Test Permeabilities—Air 58° F.

	Rated Perm.	Clogged	Gasoline	Incr.	Mur. Acid	Incr.
Average.......	39.5	15.7	17.0	1.3	20.0	3.0

Results.—Preliminary treatment in gasoline gave a small increase in permeability. The succeeding muriatic acid treatment gave a further increase, though again small.

Test 3. Nitric Acid.—Five plates were treated in nitric acid for two hours, washed and tested.

Data:

Test Permeabilities—Air 58° F.

	Rated Perm.	Clogged	Cleaned	Increase
Average..............	38.7	12.7	17.6	4.9

Results.—Treatment in nitric acid results in small increments in permeability, averaging 4.9 cubic feet.

Test 4. Chromic—Sulfuric Acid.—Two plates were soaked in a 2 per cent solution of technical dichromate of soda in sulfuric acid for one hour, washed, dried and tested.

Data:

Test Permeabilities—Air 58° F.

	Rated Perm.	Clogged	Cleaned	Increase
Average.............	38.0	9.9	23.7	13.8

Results.—The permeability increases were appreciable, although still far from the original values for the plates.

Test 5. Caustic Soda Treatment.—Plates were treated with caustic soda (20 per cent) for 0.5, 1.0 and 2.0 hours, washed, dried and tested.

Data:

Test Permeabilities

	Rated Perm.	Clogged	Cleaned	Increase
	2.0 Hours in Caustic Solution			
Average	38.8	10.0	15.4	5.4
	1.0 Hour			
Average	38.8	10.3	14.1	3.8
	0.5 Hour			
Average	38.8	13.3	22.6	9.5

Results.—Treatment of the plates in 20 per cent caustic soda produced some increase in permeability, 5.4, 3.8 and 9.5 cu. ft., respectively, for 2, 1, and 0.5 hours treatment. The results of the 0.5 hour treatment are erratic. The per cent increases in permeabilities were 39.7, 36.3 and 58.2 for the 2, 1 and 0.5 hour treatment.

Test 6. Effect of Soaking Time in Acid.—To determine the influence of the duration of the acid soaking on the efficiency of cleaning, three plates each were allowed to stand 1, 1.5 and 2 hours in muriatic acid, and chromic-sulfuric acid (2 per cent dichromate).

Data:

(A) Muriatic Acid

	Test Permeabilities			
	Rated Perm.	Clogged	Cleaned	Increase
	1 Hour Muriatic Acid			
Average	37.5	14	17.4	3.8
	1.5 Hours Muriatic Acid			
Average	37.5	16.5	20.2	3.8
	2.0 Hours Muriatic Acid			
Average	37.5	13.4	17.3	3.6
Air Temperature		50°F.	58°F.	

(B) Chromic-Sulfuric Acid (2 Per Cent)

1 Hour Chromic-Sulfuric Acid

Average	38.5	13.6	28.7	15.1

1.5 Hours Chromic-Sulfuric Acid

Average	38.5	12.3	26.5	14.3

2.0 Hours Chromic-Sulfuric Acid

Average	38.5	12.8	28.3	15.5
Air Temperature		58° F.	50° F.	
Barometric Pressure		29.15 in.	29.19 in.	

Results.—(*A*) Treatment in muriatic acid produced only a minor increase in permeability and no improved effect was shown in the longer soaking times. Increase in permeability for 1, 1.5 and 2 hours soaking were 3.8, 3.8 and 3.6 cu. ft. respectively, averaging 3.7.

(*B*) Chromic-sulfuric acid treatment resulted in appreciable increases in permeability, although soaking periods of 1.5 and 2 hours resulted in no added benefit. Increases in permeability for 1, 1.5 and 2 hours soaking were 15.1, 14.3 and 15.5 cu. ft. respectively, averaging 14.9. The average permeability after cleaning in chromic-sulfuric acid was 27.8, which is 72 per cent of the original rated permeability (38.5).

Prolonged Treatment

(1) Plates which had been treated in muriatic acid for 2 hours were given an additional 2-hour treatment, totaling 4 hrs., and re-tested.

Data:

	Test Permeabilities				
	Rated Perm.	Clogged	2 Hours	4 Hours	Increase
Average	37.5	13.8	17.3	18.0	3.6–0.7 (4.3 total)
Air Temperature	48° F.				

Results.—A second treatment of 2 hours in muriatic acid effected a negligible increase in permeability, the average increase being 0.7 cubic feet.

(2) The three plates, which had been treated one hour in muriatic acid, were treated for two hours in the chromic-sulfuric acid, and re-tested.

Data:

Plate	Rated Perm.	Clogged	Mur. Acid	Chromic-Sul. Acid	Increase
1 Top	37.5	9	14	28.2	5 –14.2
Bottom		6	10.5	33.6	4.5–13.1
2 Broken					
3 Top	37.5	22	24.5	27.9	2.5–3.4
Bottom		17	20.5	22.0	3.5–1.5
Average	37.5	13.5	17.4	27.9	3.9–8.0 (11.9 total)

Results.—In the case of Plate 1 the change resulting from the chromic-sulfuric acid treatment was comparable to the expected increase, namely 13.6 cu. ft. Plate 3 did not similarly respond, although it should be noted that the final permeability is approximately that of Plate 1. The average permeability of these plates after the chromic-sulfuric acid treatment was 27.9, or 74 per cent of the rated permeability. The combination of treatments indicated no advantage over single treatment in chromic-sulfuric acid.

(3) Plates which were treated two hours in chromic-sulfuric acid were given a duplicate treatment.

Data:

	Test Permeabilities				
	Rated Perm.	Clogged	2 Hours	4 Hours	Increase
Average	38.5	13.1	27.7	29.1	14.7–1.5 (16.2 total)

Results.—The second chromic-sulfuric acid treatment produced a slight increase in permeability, averaging 1.5 cubic feet.

(4) The plates that had been treated for one hour in chromic-sulfuric acid, were given a second soaking of 24 hours and re-tested.

Data:

	Test Permeabilities				
	Rated Perm.	Clogged	2 Hours	26 Hours	Increase
Average	38.5	13.6	28.7	31.7	15.1–3.0 (18.1 total)
Air Temperature	49° F.				

Results.—The 24-hour soaking resulted in a small increase in permeability, averaging 3.0 cu. ft. The average permeability of these plates increased from 13.6 to 28.7 and 31.7 through the cleaning process. The average final permeability was 82 per cent of the original rated permeability.

Test 7. Chromic-Sulfuric Acid (*5 Per Cent*).—Four plates were treated in 5 per cent chromic-sulfuric acid solution for one hour, one plate for 30 minutes and one plate for 15 minutes. A new unused plate was also treated for one hour and tested. Plates were then thoroughly washed, dried and tested.

Data:

	Test Permeabilities			
	Rated Perm.	Clogged	Cleaned	Increase
1 Hour Treatment				
Average	38.2	14.6	32.5	18.1
Average New Plate	36.0	36.5	37.8	1.3
0.5 Hour Treatment				
Average	38.5	13.2	28.6	15.4
0.25 Hour Treatment				
Average	38.5	9.3	27.1	17.9

Average Permeability and Change

	Average Perm. After Cleaning	Per Cent of Rated Perm.	Average Perm. Increase
1 Hour	32.5	85%	18.1
0.5 Hour	28.6	74%	15.4
0.25 Hour	27.1	70%	17.9

Results.—One-hour treatment in the chromic-sulfuric acid (5 per cent dichromate) resulted in a remarkable restoration of permeability, the final value being 85 per cent of the original rated permeability.

The shorter periods give satisfactory, but not as effective, results.

It is interesting to note the data on the new unused plate when subjected to the same tests and cleaning process. This data serves as a further check on the reliability of the testing method, and confirms the thoroughness of the washing.

Test 8. Westerly Plant Plates.—A number of plates were cleaned for the Cleveland Westerly Plant. These plates were heavily coated with iron salt and grease. The Westerly sewage is very strong and high in pickling and slaughter-house waste. The plates were in three permeability groups, 20, 40 and 60 cu. ft. per minute, although the exact rating of each plate was not known. Representative plates from each group were taken for test.

The plates were treated for two hours in 2 per cent dichromate in sulfuric acid, washed, dried and tested. The plates, as a result of this treatment, were not clean, either in appearance or permeability. The plates were then soaked in 20 per cent caustic soda solution for 24 hours, rinsed, treated with 2 per cent dichromate for two hours, and tested.

Data:

Test Permeabilities

Rated Perm. (Assumed)	Clogged	Cleaned	
		Chromic-Sulf. Acid	Caustic Chromic-Sulfuric Acid
60	12.5	35.1	50.0
40	8.2	22.1	34.4
20	4.0	8.0	21.5

Results.—Assuming permeabilities of 60, 40 and 20 the chromic-sulfuric acid treatment produced a restoration in permeabilities of 59, 55 and 40 per cent for the respective plates. The caustic and chromic-sulfuric acid treatment produced 83, 86 and 100 per cent respectively. The treatment in acid alone removed the deposited iron compound but left the grain interstices filled with a fine gray substance. The preliminary treatment in caustic solution softened the iron and made possible the removal of this and the gray deposit.

Test 9. Southerly Plant Plates.—Fifteen diffuser plates taken from the aeration tanks at the Southerly Plant were experimentally cleaned and tested, to determine the method of cleaning and the degree of improvement. The plates had been in service for two years in an aeration mixture high in iron (raw sewage, 150 p.p.m. Fe) and clogging had increased the pressure loss through the plates to an excessively high value. Upon examination after removal it was seen that the plates were covered with a dense film of iron oxide.

The original rated permeability of the individual plates was not known; the plates, however, were specified in contract to be of permeability 40 with a tolerance of 10 per cent.

At the Southerly Plant the plates were treated with a 1 to 1 solution of commercial muriatic acid (18° Baumé) for 24 hours and washed in running water for 48 hours. After natural drying for several weeks the plates were tested for permeability. The plates were later treated with 2 per cent dichromate in sulfuric acid for two hours, rinsed, dried in air, and tested.

Data:

Test Permeabilities

	Clogged	Cleaned	
		Muriatic Acid	Chromic-Sulfuric Acid
Average	0	18.5	30.3

Cleaning with muriatic acid produced an average increase in permeability from 0 cu. ft. to 18.5 cu. ft., with a possible recovery of 46 per cent of the original permeability. Successive treatments in muriatic and chromic-sulfuric acid produced an average total increase of 30.3 cu. ft. with a recovery of 75.8 per cent. After the muriatic acid treatment the plates still showed the presence of some deposited substance, while the chromic-sulfuric acid restored them to the appearance of new plates.

There is no data to show the degree of cleaning attainable by treatment with chromic-sulfuric acid alone. It is possible that the muriatic acid contributed to some extent in the combined cleaning process in its ability to dissolve the iron deposits. Previous experience has indicated the fact that in the case of plates at Easterly, which were not extremely dirty, muriatic acid will restore permeability to about 50 per cent of the original value and chromic-sulfuric acid alone to about 75 per cent; and that in the case of plates at Westerly, which were thickly covered with iron and grease, chromic-sulfuric acid alone was not entirely satisfactory, but that a preliminary treatment in caustic solution followed by chromic-sulfuric acid restored permeability to about 85 per cent for 40 and 60 plates.

Apparently muriatic acid treatment partially restores the permeability of the plates, but a combined treatment with muriatic acid and chromic-sulfuric acid (or possibly chromic-sulfuric acid alone) in the case of heavily iron-encrusted plates, will give more nearly maximum recovery.

Discussion and Conclusions

The simple permeability test apparatus suggested by Beck was found highly satisfactory for determination of permeability where extreme accuracy is not required. The average test permeability of thirteen new diffuser plates was within one per cent of the permeability rated by the manufacturer. The maximum difference between test permeability and rated permeability for one plate was less than four per cent.

In no case were air temperature and barometric pressure corrections applied since this did not appear necessary. Relative humidity varied from 40 to 80 per cent with no apparent effect on permeability. In one set of tests the relative humidity of the test air (filtered outdoor air) was 96 per cent and the permeability values were subnormal as indicated by tests on reference (new) plates. The following day with a relative humidity of 80 per cent the rates were normal.

The functioning of the permeability apparatus should be checked by first testing one or more reference plates of known permeability. Should the ratings not be normal the tests should be made at some later time when conditions are satisfactory. Damp or rainy days should be avoided as suggested by W. E. Howland (3).

The chromic-sulfuric acid cleaning agent is the only material of those employed that suitably restored porosity to the diffuser plates. From 75 to 85 per cent recovery of permeability was attained. The 5 per cent dichromate solution is slightly more effective than the 2 per cent solution, but has the disadvantage of the difficulty and care required in its preparation.

Gasoline, muriatic acid, nitric acid and caustic soda produced some cleaning effect and restoration of permeability, but these agents did not approach the efficiency of the chromic-sulfuric acid solution. The latter alone gave the plate a clean appearance.

It appears that in extreme cases, where the plates are heavily encrusted with iron and grease deposits, a preliminary treatment is required. Caustic soda is indicated as a suitable agent in the case of heavy grease. There may be some advantage in a prior soaking in muriatic acid when the occurrence of iron is severe.

In routine plate cleaning, the 2 per cent dichromate solution is recommended with a soaking time of one to two hours followed by draining and thorough washing consisting of at least ten rinsings in water. Washing by forcing water under pressure through the plates appears preferable, but requires special equipment.

In actual plant practice the plates, after a partial washing by the rinsing process, were stacked and the stacks repeatedly sprinkled and soaked thoroughly and allowed to drain. Results of plant scale cleaning were nearly equal to test runs in restoration of permeability.

Since this work was done, Calkins, chief chemist at the Toledo Sewage Plant, suggested the use of Santomerse, a new wetting agent, in the plate washing. Santomerse has a remarkable quality of greatly increasing the penetrating and cleansing ability of water, and because of this may simplify the washing process.

References

1. Engineering *Bulletin* No. 1, Third Edition, Carborundum Co., p. 21.
2. *Sewage Works Journal,* 8, 22–37 (Jan., 1936).
3. *Sewage Works Journal,* 8, 485–488 (May, 1936).

PART II. DIFFUSER PLATE CLEANING VS. COMPRESSED AIR COSTS

It has been shown that it is possible to recover much of the usefulness, or in this case permeability of aeration diffusers, by cleaning. These questions then arise: How much does it cost? When should diffuser plates be cleaned? What is the breakage? How many times can the porosity be restored by cleaning?

Cost of Cleaning Aeration Diffuser Plates

The largest item of cost is the labor required to remove, clean and replace the diffusers estimated as follows:

Labor cost of removing a diffuser plate	$0.04
Labor cost of cleaning and washing plates	0.05
Labor cost of replacing a diffuser plate	0.04
Total labor	$0.13

All of the acid cleaning was done in the aeration tank gallery 16 ft. above the elevation of the diffuser plate holders, making it necessary to lift the plates from the aeration tank bottom to the gallery. The cleaning was not done in the aeration tanks because the work was planned during cold weather when the regular outside labor could be used to advantage.

Chemicals used to make up the 2 per cent solution of chromic acid are commercial sulfuric acid purchased in 200 pound carboys at 2 cents per pound and potassium dichromate at 8.5 cents per pound delivered in wooden barrels.

Cost of chemicals for cleaning one plate	$0.09
Misc. costs: Rubber gloves, boots and aprons; earthenware crocks, acid pitchers—per plate	0.01
Labor	0.13
Total cost per plate—labor and material	$0.23

All figures are based upon cleaning plates in lots over 1,000 and the time of at least three men. Common labor receives 72.5 cents per hour at the Cleveland plants. Based on these figures, the cost of cleaning all diffusers at the Easterly Plant would be slightly over $5,000.

When Should Diffuser Plates Be Cleaned?

The question of when to clean diffuser plates is slightly complicated by factors that cannot be easily determined in the average sewage plant. There is usually a sequence of events that occur which finally causes the plant operator to wonder whether his plate is clogged. In plants equipped with electrically driven compressors an increase in power cost occurs, motors are overloaded, discharge air is too hot, and lubrication trouble appear in the blower. With gas engines the trouble may be high gas or oil consumption, a noisy blower, too hot air discharge, or the by-pass burnt by hot air. All these symptoms indicate that the loss of head through the diffuser plate is too great. Experience in Cleveland and elsewhere has demonstrated that when the permeability of a diffuser plate in service drops below twelve it is time to clean.

The operator should study systematically the year-to-year power costs in relation to unit volume of compressed air. For convenience a million cubic feet has been selected as a unit because that is roughly the quantity of air required for one million gallons of average sewage

Table I.—*Relation of Blower Discharge Pressure to Cost of Air*

	Discharge Pres., Lb. Per Sq. In.	K.W.H. Required Per Million Cu. Ft. Air	K.W.H. Cost Per M.G.	Yearly Cost [1]
1939	6.8	400	$2.68	$ 89,907
1940	7.2	463	3.10	92,554
1941*	7.8	548	3.67	117,016

[1] Based on 1.0 cu. ft. of air per gallon of sewage and 0.67 cents per K.W.H.

* Estimated.

(suspended solids from 250 p.p.m. to 300 p.p.m.). This relationship is shown for the Easterly Plant in Table I.

This table shows that an increase in blower discharge pressure of 1.0 lb. per sq. in. adds approximately one dollar to the cost of treatment of each million gallons under Cleveland conditions. Obviously in a large plant this increase could not be allowed to continue. Therefore plate cleaning is in order in this case at one-half pound increase in discharge pressure, which is the point where the permeability is around twelve. Due to the day-to-day natural variation in air pressure the increase should be computed from monthly average reading. One-half pound increase is a practical figure which avoids quibbling over tenths of pounds. The $5,000 cleaning charge is more than offset by reduced power cost. Air distribution improves and control is much simpler.

Much of this work was done at Cleveland before the plant shut down due to financial troubles early in 1941. A tabulation of the monthly discharge pressures in Table II shows a gradual increase through 1939 and 1940, followed by a sudden rise of 0.6 lb. immediately after the plant was started again in March, 1941.

Table II.—*Blower Discharge Pressure*
Pounds per Square Inch

	1939	1940	1941
Jan.	6.80	6.92	7.27
Feb.	6.50	6.83	6.83*
Mar.	6.50	6.80	8.13
Apr.	6.80	7.21	8.05
May	6.80	7.27	7.67
June	6.80	7.35	8.10
July	6.90	6.93	7.86
Aug.	6.90	6.89	
Sept.	6.80	7.06	
Oct.	6.80	7.18	
Nov.	6.80	7.31	
Dec.	6.80	7.40	
Average	6.8	7.1	7.8

* Plant of operation part of month, omitted from average calculation.

TABLE III.—*Tested Plates of Batches Cleaned for No. 5 and No. 10 Aeration Tanks*

Original Permeability		Permeability After Treatment		Per Cent Recovery	
No. 5	No. 10	No. 5	No. 10	No. 5	No. 10
36	36	27.0	28.0	75.0	77.8
37	37	27.75	27.75	75.0	75.0
38	38	29.25	29.25	77.0	77.0
39	39	24.75	25.25	63.5	64.7
40	40	23.75	23.50	59.4	58.8
41	41	29.25	28.50	71.3	69.5
42	42	27.25	27.25	64.5	66.1
43	43	24.25	24.0	56.4	55.8
			Average	67.8	68.1
36	36	26.0	27.0	72.2	75.0
37	37	29.0	28.75	78.4	77.7
38	38	29.75	29.75	78.3	78.3
39	39	27.75	27.50	71.2	70.5
40	40	30.25	29.25	75.6	73.1
41	41	33.50	31.50	81.7	79.3
42	42	35.25	33.50	83.9	79.8
43	43	37.0	35.25	86.0	82.0
			Average	78.4	77.0
36	36	26.25	26.1	73.6	72.6
37	37	24.75	25.25	66.9	68.2
38	38	28.0	27.75	73.7	73.0
39	39	24.50	24.50	62.8	62.8
40	40	31.0	30.25	77.5	75.6
41	41	32.75	31.75	79.9	77.4
42	42	33.0	33.0	78.6	79.1
43	43	39.0	34.0	90.6	79.1
			Average	75.4	73.4
	36		22.50		62.5
	37		21.50		58.1
	38		27.0		71.1
	39		33.50		85.9
	40		31.50		79.4
	41		18.75		45.8
	42		27.50		65.5
	43		31.75		73.8
			Average		67.8
			Grand average	73.9	71.8

The folly of shutting down a major plant is quickly learned by those responsible for operation. There is no doubt that plates allowed to stand dirty and idle for even a short period of time will rapidly decrease in porosity. This costs the public many thousands of dollars.

By August, 1941, it was possible to reduce the pressure from 8.1 to 7.8 lb., a reduction of 0.3 lb. If another shut-down does not occur this winter, the pressure will probably be back to normal by the summer of 1942.

Increase in Permeability by Cleaning

The importance of keeping continuous records on the cleaning crew cannot be overstressed. If the cleaning is not watched closely, the acid solution may deteriorate or the thorough water-wash after the acid bath neglected. The best way to overcome these hazards is to select sample plates from a cleaned batch and test for increase in permeability. By so doing an average recovery figure can be computed, that tells accurately the condition of the entire batch.

Two sample test runs have been included in Table III showing the variation in sample plates.

The averages are considered good because they are close to 75 per cent recovery. The best recovery obtained under laboratory control on small experimental lots was around 80 per cent.

Summary

It has been demonstrated that aluminum oxide diffuser plates can be removed and cleaned economically from the Burger type holders on a full plant-scale basis.

The cost of plate cleaning, including labor for removal and resetting is just under twenty-five cents per plate.

There is no appreciable loss due to plate breakage or torn rubber gaskets.

It is sound economy to clean diffusers when the blower discharge pressure increase equals one-half pound per square inch and the plate permeability has dropped to about twelve.

The question of how many times a plate can be cleaned before the porosity is permanently lost is still a matter for investigation.

OPERATING COSTS IN FIFTEEN ILLINOIS SEWAGE TREATMENT PLANTS *

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In many reports of cost data that have appeared in the literature, information on important factors that directly affect the operating costs has been omitted, thus leading to erroneous conclusions as to the economy of operation of the plants. Local conditions affect costs to such an extent that they should be carefully studied before any comparison of unit costs is made. In this article the writers have attempted to present all salient data that should be studied in conjunction with the cost data.

Of the plants studied, thirteen are operated under the Illinois Sanitary District Act of 1917, while the remaining two derive their operating revenues from sewer service charges. The cost data from these plants were obtained from auditors' or superintendents' yearly reports.

Only information on direct operating costs has been included in this study, since they seem to be more variable than the other costs. Charges for bond retirement and interest may be calculated exactly for each plant. Administration costs constitute, on the whole, a relatively small percentage of the operating costs, and depreciation charges cannot be calculated with any degree of accuracy since the length of service of the plant units cannot be estimated closely.

Ad—Activated Sludge—diffused air.
Am—Activated Sludge—mechanical aerators.
C—Combined Sewage.
Co—Air Compressors.
Cu—Comminutor.
EP—Effluent Pumps.
F—Flocculators.
Fn—Trickling Filters—nozzle distribution.
Fr—Trickling Filters—rotary distribution.
G—Grease Removal Equipment.
GR—Grit Removal Equipment.
I—Imhoff Tanks.
L—Lights.
M—Chemical Precipitation.
P—Sewage Pumps.
PS—Primary Tank Mechanisms.
RP—Effluent Recirculation Pumps.
S—Sanitary Sewage.
SP—Sludge Pumps.
SS—Separate Sedimentation and Sludge Digestion.
ST—Secondary Tank Mechanisms.
T—Screen Cleaning Mechanisms.

* From *Operating Costs in Fifteen Illinois Sewage Treatment Plants*, Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering in the Graduate School of the University of Illinois, 1941.

TABLE 1A.—*General Information*

Plant	Type of Units	Year Built	No. of Years Included in Study	Construction Costs—Dollars: Construction of Plant (*a*)	Construction Costs—Dollars: Land	Construction Costs—Dollars: Total (*a*)	Construction Costs—Dollars: Per Capita (*b*)	Population: 1940 Census	Population: Design	Population: Present Connected (*c*)	Population: Load Factor % (*d*)	Sewage Flows: Type of Sewage	Sewage Flows: Per Capita Flow, Gal. Per Day	Sewage Flows: Flow Per Year, Million Gallons	Sewage Flows: Flow Per Year, Given Complete Treat.
Activated Sludge															
Belvidere	SS, Am	1937	3	—	—	150,000	15.00	8,194	10,000	8,100	0.81	S	99	302	302
Chicago Heights (*e*)(*f*)	SS, Ad	1936	2	—	—	251,127	8.37	22,461	30,000	22,800	0.76	C, W	82	686	686
Kewanee	SS, Am	1937	3	—	—	146,000	7.30	16,901	20,000	8,000	0.40	S	104	304	304
Springfield (*e*)	SS, Ad	1929	3	728,800	12,800	741,600	8.24	(*x*)	90,000	80,000	0.89	C	96	2,810	2,810
Trickling Filters															
Aurora (*e*)	SS, Fn	1929	3	—	—	730,000	10.90	(*x*)	67,000	49,000	0.72	C	140	2,500	2,082
Bloomington-Normal (*e*)	I, Fn	1928	2	637,950	25,350	663,300	12.06	39,851	55,000	39,000	0.71	C	110	1,560	1,560
Clinton (*e*)	I, Fr	1935	3	—	—	(*h*) 92,100	7.67	6,331	12,000	6,000	0.50	C	145	318	301
Decatur (*e*)	Ad, I, Fn (*g*)	1924	3	1,012,500	15,300	1,027,800	17.13	59,305	60,000	50,000	0.83	C, W	225	4,115	4,115
DeKalb (*e*)	SS, Fn	1930	3	159,970	3,730	163,700	10.46	9,146	16,000	8,400	0.52	S, W	131	399	387
Elgin (*e*)	SS, I, Fn	1926	2	514,750	9,000	523,750	13.09	38,333	40,000	33,000	0.83	C	133	1,612	1,612
Galesburg (*e*)	SS, Fn	1932	3	337,550	11,600	349,150	14.36	28,876	24,000	26,000	1.08	C	123	1,167	1,076
Hinsdale (*e*)	I, Fn	1930	3	303,790	37,910	341,700	18.47	11,661	18,500	10,000	0.54	C	294	1,074	621
Urbana-Champaign (*e*)	I, Fn	1924	3	498,280	9,550	507,830	11.29	47,168	45,000	43,000	0.96	S	83	1,302	1,121
Chemical Precipitation															
Danville (*c*)	M, SS	1937	2	—	—	215,469	5.39	36,919	40,000	28,000	0.70	C	125	1,278	—
Waukegan (*e*)	M, I	1937	2	—	—	(*i*) 600,000	12.00	34,241	50,000	32,000	0.64	C	118	1,384	—

TABLE IB.—*Analyses, Power, Employees*

Plant	Analytical Data: B.O.D. Influent, P.P.M.	B.O.D. Effluent, P.P.M.	B.O.D. Per Cent Removal	Population Equivalent	Suspended Solids Influent, P.P.M.	Suspended Solids Effluent, P.P.M.	Suspended Solids Per Cent Removal	Uses of Power	K.W.H. Purchased Per M.G.	Unit Cost Per K.W.H. (Cents)	Sewage Pumping Head, Feet	Supt.	Chemist	Foreman	Mechanic	Operators	General Labor and Miscellaneous
Activated Sludge																	
Belvidere	201	10	95	8,190	198	6	97	Am, L, PS, SP, ST	367	2.3	0	1	—	—	—	1	1
Chicago Heights (*e*)(*f*)	236	16	93	21,800	320	20	94	Co, (*k*), L, PS, SP, ST, T	134	1.5	23 (*t*)	1	1	—	—	2	—
Kewanee	422	12	97	17,000	(*j*)			Am, Cu, L, PS, SP, ST, (*m*)	192	1.6	0	—	—	—	—	1	—
Springfield (*e*)	169	14	92	63,300	191	12	94	Co, (*n*), L, PS, SP, ST, T	98	1.2	0	1	1	1	1	5	7
Trickling Filters																	
Aurora (*e*)	124	17	86	41,600	172	24	86	L, PS, SP, ST, T, (*o*)	39	2.5	25	1	1	—	—	3	2
Bloomington-Normal (*e*)	150	13	92	31,400	161	20	88	GR, L, P, ST, T	125	1.7	28	1	1	—	—	6	1
Clinton (*e*)	(*J*)	—	—	—	—	—	—	L, SP	2.3	3.7	0	1	—	—	—	1	—
Decatur (*e*)	199	24	87	109,000	209	37	82	Co, (*p*), GR, EP, L, SP, ST, T	(*r*)	(*r*)	0 (*u*)	1	1	1	—	7	1
DeKalb (*e*)	256	19	92	13,700	285	22	92	L, PS, SP, ST, RP, T	65	2.4	0 (*v*)	1	—	—	1	—	—
Elgin (*e*)	123	34	72	26,400	141	31	78	L, PS, SP, ST	12	1.8	0	1	1	1	1	4	—
Galesburg (*e*)	162	28	83	25,300	196	27	86	L, P, PS, SP, ST, T	204	1.5	27	1	1	—	—	4	4
Hinsdale (*e*)	152	14	91	12,700	(*j*)	—	—	GR, L, P, SP, T	217	1.0	30	1	—	—	—	2	—
Urbana-Champaign (*e*)	255	22	91	44,500	229	27	88	L, P, SP, ST	(*r*)	1.7 (*s*)	24	1	1 (*w*)	—	—	4	1
Chemical Precipitation																	
Danville (*e*)	185	87	53	31,900	148	58	60	Cu, F, L, PS, SP	(*r*)	2.8 (*s*)	0	1	1	—	—	4	1
Waukegan (*e*)	195	95	51	34,200	201	50	75	F, G, GR, L, P, PS	169	1.6	22	1	1		1	6	—

W—Industrial Wastes.
Chicago Heights—Steel, Chemical and Brewery Wastes.
Decatur—Starch Wastes.
DeKalb—Canning Wastes.

a—Includes all additions subsequent to original plant.
b—Based on design population of the smallest plant unit.
c—Superintendent's estimate.
d—Ratio of connected population to design population.
e—Sanitary District.
f—Bloom Township Sanitary District.
g—Pre-aeration plant operated for only a short time each year.
h—Includes cost of pumping station in city.
i—Estimate by plant superintendent.
j—B.O.D. and suspended solids not determined at Clinton. Suspended solids not determined at Kewanee or Hinsdale.
k—Auxiliary compressors only—gas engines operate remaining compressors.
m—59 per cent of power generated at plant by generators operated by sewage gas engines.
n—Two compressors only—remaining compressors operated by sewage gas engines.
o—Sewage pumps operated by gas engines.
p—Used for pre-aeration plant which is used for only a short time each year.
r—Information not available.
s—Estimate by plant superintendent.
t—40 per cent of incoming sewage pumped at plant.
u—During times of high river flow it is necessary to pump plant effluent to river level.
v—During canning season part of plant effluent is returned to influent channel for dilution purposes.
w—Part time.
x—District served by treatment plant includes some unincorporated areas, and population of district areas not available at the time this article was written.

General Information

In Tables IA and IB all factors are given that the writers feel should be considered in conjunction with the operating costs. The construction costs shown have been included as a matter of general interest.

The load factor (the ratio of the present connected population to the design population) is an important item to be considered. It would seem probable that an increase in the load factor would not bring about a proportionate increase in the unit costs, and therefore a plant with a small load factor might be expected to have higher unit costs than one with a connected population almost equal to the design population, provided other conditions remained the same.

The amount and strength of sewage treated and the degree of treatment required naturally affect the unit costs. Industrial wastes, such as are found at some of the plants, require more careful treatment and thus tend to increase costs. At some plants the condition of the outlet stream is such that only primary treatment is required at certain times, thus materially lowering pumpage and other costs. The two plants employing chemical precipitation add chemicals during only about three to four months of the year.

The uses of power vary greatly. At some plants flow is by gravity throughout the entire treatment process, while at others sewage must be pumped. Some have Imhoff tanks while others have sedimentation tanks with mechanical sludge removal equipment. Some generate power with gas engines. All these and many other differences in power uses, together with the variation in the unit power price, affect the costs.

In the final columns of Table IB are shown the numbers of each type of employees at each plant. These were added as items of general interest. They include only regular employees and do not show extra labor hired for short periods of time.

Operating Costs

In Table II are shown the percentages of each operating dollar chargeable to labor, power, supplies and equipment, repairs and renewals, and miscellaneous costs. Also shown are the cost per capita, based upon both the connected population and the population equivalent, the cost per million gallons given complete treatment, and the cost per pound of B.O.D. removed. For the chemical precipitation plants, the cost per million gallons is based on all sewage received at the plant, since only primary treatment is maintained during most of the year.

Table II.—*Cost Data*

Plant	Percentage of Total Cost					Unit Cost—Dollars			
	Labor	Power	Supplies and Equipment	Repairs and Renewals	Miscellaneous	Per Capita (Based on Connected Pop.)	Per Capita (Based on Population Equiv.)	Per Million Gallons given Complete Treatment	Per 1000 Lbs. B.O.D. Removed
Activated Sludge									
Belvidere	53.5	38.3	5.8	1.3	1.1	0.81	0.80	21.64	13.52
Chicago Heights	67.3	12.4	8.6	3.1	8.6	0.49	0.51	16.33	8.80
Kewanee	47.5	23.6	15.7	7.8	5.4	0.51	0.24	13.53	4.11
Springfield	67.3	7.7	16.7	—	8.3	0.54	0.69	15.48	11.99
Trickling Filters									
Aurora	74.5	8.2	3.2	5.4	8.7	0.51	0.60	11.94	12.16
Bloomington-Normal	54.6	11.9	20.7	6.2	6.6	0.71	0.88	17.66	15.55
Clinton	82.0	0.7	4.8	1.1	11.4	0.65	—	12.85	—
Decatur	66.8	16.5	4.3	7.5	4.9	0.53	0.27	7.12	4.75
DeKalb	66.4	13.9	6.3	4.4	9.0	0.63	0.38	11.57	6.89
Elgin	76.4	1.5	3.9	7.5	10.7	0.67	0.84	13.79	18.82
Galesburg	68.2	13.6	4.1	3.9	10.2	1.02	1.05	22.72	23.67
Hinsdale	67.7	15.4	—	—	16.9	0.89	0.70	14.35	12.45
Urbana-Champaign	62.5	18.2	10.9	4.7	3.7	0.37	0.36	14.17	7.30
Chemical Precipitation									
Danville	56.9	4.8	7.5	26.6	4.2	0.72	0.63	15.73[a]	19.06
Waukegan	59.9	13.8	19.3	5.1	1.9	0.83	0.78	19.22[a]	23.91

[a] Based on all sewage received at plant.

In most presentations of cost data, the unit costs are given on the bases of population served and the quantity of sewage treated. On the first basis, no weight is given to either the quantity and strength of the sewage treated or the efficiency of the treatment process in doing its required work. On the second basis, the quantity of sewage is taken into account, but its strength and the efficiency of treatment are ignored. The two other bases used in this paper, the population equivalent and the pounds of B.O.D. removed, take into account more of the remaining factors and therefore may appear to be more sound. In calculating the population equivalent the strength and quantity of sewage are used, while in calculating the pounds of B.O.D. removed the efficiency of the process is included, in addition to the strength and quantity values. It must be remembered, however, that the latter two bases depend on the

Table III.—*Range of Unit Costs—All Types of Plants*

	Chemical Precipitation (2 Plants)	Trickling Filters Sewage Not Pumped (3 Plants)	Trickling Filters Sewage Pumped (6 Plants)	Activated Sludge Mechanical Aeration (2 Plants)	Activated Sludge Diffused Air Aeration (2 Plants)
Per Capita (Connected Pop.)					
Minimum	$0.72	$0.51	$0.37	$0.51	$0.49
Maximum	0.83	0.67	1.02	0.81	0.54
Per Capita (Population Equiv.)					
Minimum	$0.63	$0.60	$0.27	$0.24	$0.51
Maximum	0.78	0.84	1.05	0.80	0.69
Per M.G. Treated					
Minimum	$15.73	$11.94	$ 7.12	$13.53	$15.48
Maximum	19.22	13.79	22.72	21.64	16.33
Per 1000 lb. B.O.D. Removed					
Minimum	$19.06	$12.16	$ 4.75	$ 4.11	$11.99
Maximum	23.91	18.82	23.67	13.52	13.52

accuracy and frequency of the B.O.D. determinations. Therefore under certain conditions they may not be as sound as the older bases. At best the accuracy of the determination of unit cost on any of these bases may be questionable.

In Table III are shown the ranges of unit costs found in the various types of plants studied. No averages are included, since they would have little or no value because of the variance in conditions at the plants.

The trickling filter plants have been divided into two groups: those where it is necessary to pump sewage, and those where it is not. Under the former group are included Bloomington-Normal, Decatur, DeKalb, Galesburg, Hinsdale, and Urbana-Champaign, while in the latter group are Aurora, Clinton, and Elgin. Sewage is pumped at Aurora, but the pumps are operated by sewage gas engines, thus eliminating the power costs for pumping. At DeKalb and Decatur pumping is not carried on throughout the entire year, but industrial wastes present in the sewage require more treatment, which results in the increased use of power. This brings the power consumption to a point about equal to that found in the plants requiring year-round pumping.

The activated sludge plants have been divided into two groups: mechanical aeration and diffused air aeration. The Chicago Heights plant is the only one in either of these groups pumping sewage, and it pumps only 40 per cent of the incoming sewage.

TABLE IV.—*Distribution of Costs—All Types of Plants*

Type	No. of Plants	Percentage for		
		Labor	Power	Other Costs
Chemical Precipitation......	2	58	9	33
Trickling Filters (Sewage not Pumped)...	3	78	3	19
Trickling Filters (Sewage Pumped).......	6	63	15	22
Activated Sludge (Diffused Air Aeration)..	2	67	10	23
Activated Sludge (Mechanical Aeration)...	2	50	31	19

In Table IV is shown the distribution on a percentage basis of the costs found in the plants studied. As can be seen from the table, percentages of the total costs chargeable to labor, power, and other costs vary widely with the type of treatment.

EFFICIENCIES OF THE TYPES OF TREATMENT PROCESSES

While this article was written primarily to show the unit operating costs, data were also collected giving the efficiency of B.O.D. and suspended solids removal by the plants. These data are summarized in Table V and are added as information of general interest.

TABLE V.—*Range of Efficiency of Treatment—All Types of Plants*

	Chemical Precipitation (2 Plants)	Trickling Filters (9 Plants)	Activated Sludge Mechanical Aeration (2 Plants)	Activated Sludge Diffused Air Aeration (2 Plants)
Percentage Removal of B.O.D.				
Minimum..............	51	72	95	92
Maximum.............	53	92	97	93
Average...............	52	85	96	92
Percentage Removal of Suspended Solids				
Minimum..............	60	78	*	94
Maximum.............	75	92	*	94
Average...............	68	85	97	94

* In this group Kewanee does not run suspended solids tests.

Sewage Research

A LABORATORY STUDY OF THE GUGGENHEIM BIO–CHEMICAL PROCESS *

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The experiments upon which this report is based have been carried on during the past two years at the laboratory of Guggenheim Brothers in New York City. The authors have been assisted in the bacteriological work by Dr. J. M. Jablonowitz and in the chemical work by Messrs. J. B. Rabbage, M. F. Qualey, R. L. Williams and W. B. Fryer.

Briefly, the Guggenheim Process of sewage treatment involves the addition to the inflowing sewage of return sludge, and a solution of ferric sulfate or equivalent coagulant; followed by aeration, sedimentation, discharge of the purified supernatant, and return of a portion of the sludge. In these operational features, therefore, the process resembles a combination of chemical precipitation and activated sludge treatment.

Actually, studies carried out during the early development of the process, and subsequently, indicated certain distinct advantages over what might be expected from such a combination, noticeably in a shortening of the necessary reaction period. It was believed that some novel mechanism or reaction had been introduced and the name Bio-Chemical Process was adopted to suggest this novel feature. The present studies were undertaken therefore not so much to test or demonstrate the indicated advantages as to learn through carefully controlled laboratory experiments as much as possible of the fundamental principles upon which the operation of the Bio-Chemical Process depends.

SECTION I

Small Scale Laboratory Experiments

From these studies certain rather definite conclusions have been formulated. It will be helpful, we believe, to depart from the usual form of a report upon experimental work and state these conclusions in a series of propositions, with the supporting experimental evidence following each proposition.

(1) *The presence of ferric sulfate stimulates the growth of certain bacteria and increases the rate of bio-chemical oxidation.*

On this proposition there are several lines of experimental evidence. The initial studies were made with pure cultures of *Aer. aerogenes* and

* Presented at the Second Annual Convention of the Federation of Sewage Works Associations, New York City, Oct. 9, 1941.

of organism "87," one of the zoogleal organisms isolated and studied by Dr. C. T. Butterfield of the U. S. Public Health Service Laboratory at Cincinnati, to whom we are indebted for this culture. Freshly inoculated broth cultures of each of these organisms were treated with ferric sulfate in various concentrations. Multiplication, as indicated by development of turbidity and floc, was progressively stimulated by treatment with iron up to about nine parts per million. The effect of the coagulant itself was eliminated by addition of sulfuric acid and comparison of residual turbidities with control tubes.

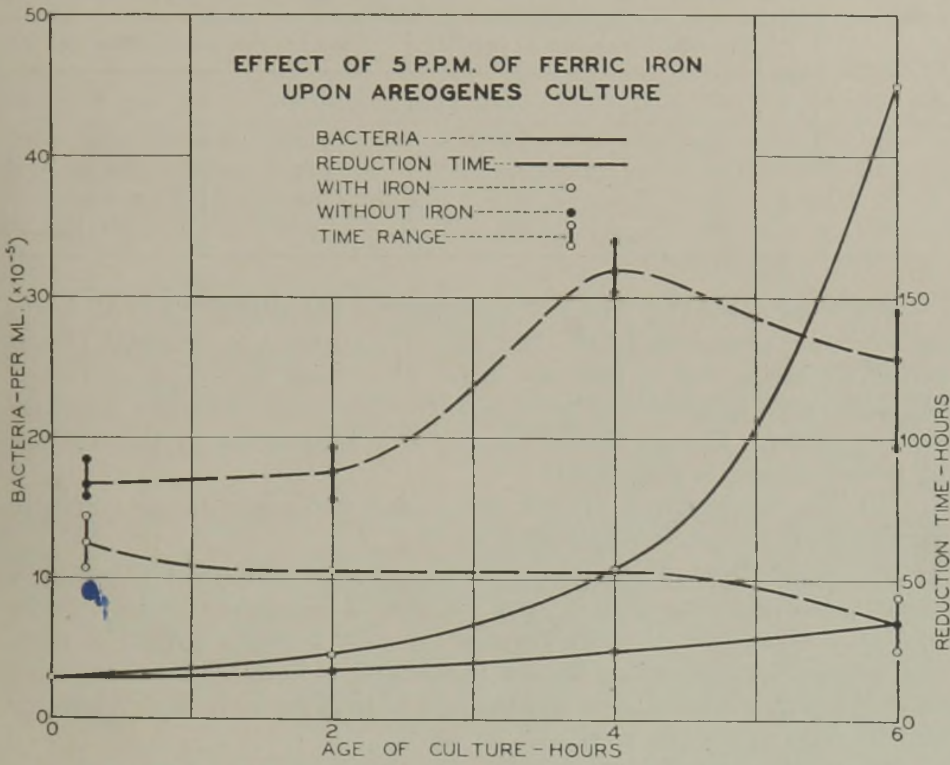

FIG. 1. Plotting of data of Table I.

Table I and Fig. 1 give some of the details of a more instructive experiment, typical of several of the same sort. Two parallel cultures of aerogenes were prepared in "synthetic sewage" as developed at the Cincinnati laboratory for oxidation studies. As used in our work this medium had a 5-day B.O.D. of about 200 p.p.m. One culture was treated with 5 p.p.m. of ferric sulfate (Column Fe), the other serving as a normal control (Column O). Both were continuously aerated and examined at the times indicated.

The plate counts need little comment. In the presence of iron floc, even when minutely subdivided, clumping of organisms tends to yield too low results so that the disparity between the two sets is probably greater than indicated. Increased rate of multiplication is evident in the Fe series as compared with the control.

The reduction time was determined by removing a 10 ml. sample, adding a drop of .05 per cent methylene blue, sealing and storing at 37° C. Decolorization occurring during the night could be recorded only as between the limits of two observations. This test indicates the "activity" of the culture in the presence of abundant food and a limited and approximately constant supply of oxygen.

TABLE I.—*Effect of Ferric Sulfate Upon a Culture of Aerogenes*

Time (Hr.)	Plate Counts (Thousands per ml.)		Methylene Blue, Reduction Time (Hr.)	
	Fe	O	Fe	O
0	300	300	55–72	80–90
2	480	340	53	80–96
4	1130	490	51	152–168
6	4500	630	25–43	98–144

It is to be noted that this reduction time is but slightly if at all modified by actual numbers in the two sets. It appears to decrease slowly in the Fe series and to increase in the O series. The striking fact is the difference between the two; a difference which becomes progressively greater. Clearly the presence of iron is speeding up the reaction by which oxygen is consumed.

(2) *The combination of iron floc and B-aerogenes in pure culture may be made to simulate activated sludge.*

Following these preliminary tests an attempt was made to set up a system, still working with a pure culture of *aerogenes* and synthetic sewage, and capable of operating continuously through a cycle of feeding, aerating, withdrawing mixed liquor and refeeding. It was found possible, after some failures, to maintain pure cultures in the system for several days or up to a week.

In a typical experiment of this series, two jars were set up, each containing three liters of synthetic sewage inoculated with *aerogenes*. One was treated with ferric sulfate (5 p.p.m. Fe), the other operated as a control. After aerating for various lengths of time, one liter of the mixed liquor was drawn off and replaced by a liter of synthetic sewage. For two days this was done twice a day at six-hour intervals. On the third day feeding was done three times at two-hour intervals. Just after the last feeding and again two hours later samples of mixed liquor were removed for a 5-day B.O.D. determination upon the total mixed liquor and upon filtered samples. Reduction of B.O.D. in the filtered sample was indicative of adsorption of soluble material; reduction of B.O.D. in the unfiltered sample, of oxidation.

The results obtained are shown in Table II and Fig. 2.

TABLE II.—*Reduction of 5-day B.O.D. During Two Hours Aeration; Aerogenes Culture*

(Per cent)

	With Iron (5 p.p.m.)	Without Iron
By adsorption from solution	61	26
By oxidation	49	26

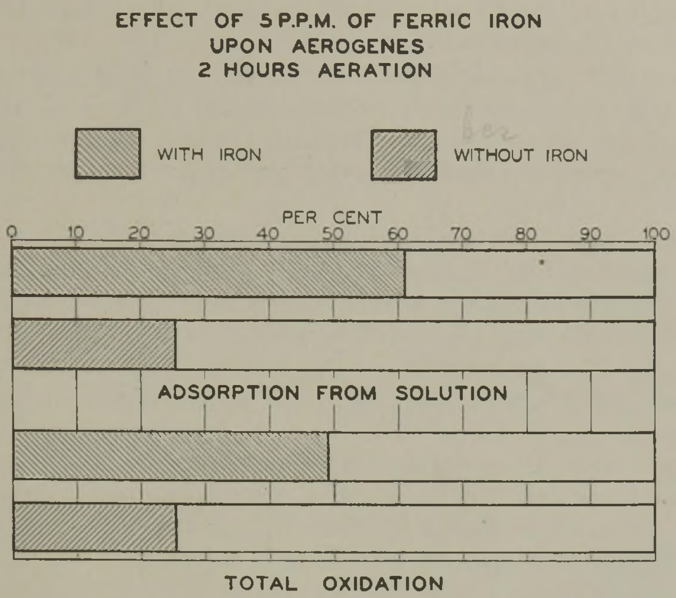

FIG. 2. Plotting of data of Table II.

This pure culture work could not be continued for more than a few days because of contamination, and no effort was made at this stage to duplicate actual plant conditions or efficiency. These experiments did demonstrate, however, that the two essential properties of activated sludge, rapid adsorption by a matrix heavily seeded with an oxidizing organism, and rapid oxidation of the adsorbed material, could be developed by suitably conditioning a mixture of iron floc and *aerogenes*.

We noted also that, without the aid of the iron, the *aerogenes* may build up a sludge having properties similar to those of the iron-bearing sludge, but to a lesser extent. As compared with a normal rate of oxidation of about 20 per cent per day, a rate of about 26 per cent in two hours means a definite accumulation of something simulating activated sludge. Similar observations have been reported in the Cincinnati studies.

In the presence of iron floc this phenomenon is magnified, yielding even under these crude conditions rates of adsorption (clarification), and of oxidation, quite comparable with activated sludge data. As we interpret them, these experiments, which were repeated many times under various conditions, indicate a somewhat novel phenomenon. The newly added iron effects coagulation and the accumulated floc, adsorption, in accordance with principles established early in the history of sewage treatment, and recently thoroughly explored and developed in the work of Rudolfs and his associates. Normally, the adsorptive capacity of the iron becomes saturated in one treatment, but in a system of recirculation, opportunity is provided for the growth of heavy concentrations of such organisms as *aerogenes,* commonly present in sewage, which in turn perform an oxidizing function and maintain the resultant sludge in an activated condition.

Thus we have a ready made matrix, rich in food supply, in which bacteria such as *aerogenes,* themselves devoid of the self-agglutinating principle of the zoogleal organisms, are enabled to multiply and subsequently to function after the manner of the activated sludge organisms.

(3) *The adsorptive power of ferric hydroxide floc is greater than that of normal activated sludge, equally well conditioned, and, in the presence of sewage bacteria, adsorption by the ferric floc will eventually eliminate adsorption by the activated floc.*

This point is demonstrated in the following series of experiments. An activated sludge was built up in the usual manner from domestic

TABLE III.—*Effect of Ferric Sulfate Upon Activated Sludge*

	B.O.D. Change During 6-hour Period (Per Cent). Adsorbed	Oxidized
1st day		
With iron	54	36
Without iron	52	19
2nd day		
With iron	92	14
Without iron	58	22

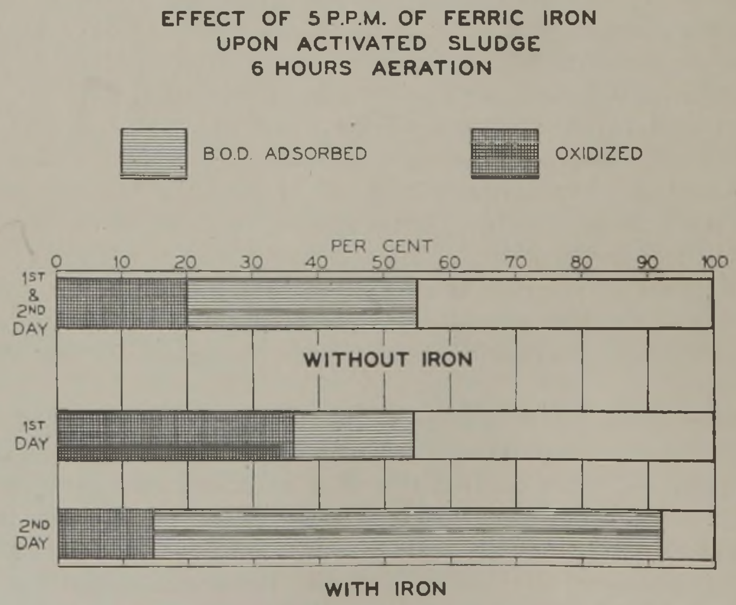

FIG. 3. Plotting of data of Table III.

sewage. When well developed, it was separated into two portions, each of which was thereafter fed at 9 A.M. and 3 P.M. daily with synthetic sewage and continuously aerated. In one case 5 p.p.m. of ferric sulfate was added with the sewage. Samples were withdrawn as previously just after feeding and at the end of the six-hour aeration period. The results on the first and second day are shown in Table III and Fig. 3.

On the first day the adsorption by the activated sludge was not influenced by the presence of the iron, but a distinct speeding up in oxidation rate is noticeable. On the second day the control was a trifle better but a striking change occurred in the presence of iron. Adsorption was greatly accelerated, 54 to 92 per cent, but oxidation declined, 36 to 14 per cent.

This phenomenon was observed several times in the course of various experiments. In keeping with our theory of the properties of the conditioned iron sludge it can only indicate that the iron floc adsorbs more readily than the activated floc. Thus the presence of both types of adsorbant, in the absence of normal sewage bacteria, leads to a starvation of the activated sludge through selective adsorption and failure to oxidize because of the absence of bacteria which are capable of developing in the iron sludge.

The system, activated sludge plus iron plus sterile sewage, is not self-sustaining. It eventually loads itself to failure by accumulation of undigested food. The result would be quite different, of course, with normal sewage, in which a varied bacteria flora permits the iron system to dominate within a short time.

More extensive data upon this point were later obtained in a series of parallel jar experiments, one with activated sludge and one with Bio-Chemical sludge. These were run continuously for a period of several weeks under varying operating conditions. During one week these conditions were: settling, decanting as completely as possible, re-feeding, aerating two hours for two cycles and overnight for the third. Samples were taken at the beginning and end of the last two-hour aeration period. In this experiment, it was possible to compute an "immediate adsorption" by comparing the B.O.D. results immediately after feeding (one or two minutes), with those computed from the analyses of the synthetic sewage, the B.O.D. of which was all in solution. By reason of its small volume and low dissolved B.O.D. the residual (return) sludge is not accounted for in this computation. The adsorption values therefor are slightly low. The results are shown in Table IV and Fig. 4.

This table and chart illustrate in particular the rapid initial adsorption of soluble organic matter, amounting to 29 per cent in the first minute or two after feeding. Conditions are not strictly comparable by reason of the greater amount of accumulated suspended solids in the biochemical system, but we note that, with about twice the suspended solids, the immediate adsorption is about four-fold. After two hours, adsorption is about the same in the two systems and oxidation is considerably greater in the activated sludge system.

TABLE IV.—*Comparison of Biochemical and Activated Sludges in Continuous Experiment*
Immediate adsorption, synthetic sewage, total adsorption, and oxidation after two hours

	(Ave. of 5 daily sets of values) 5-Day B.O.D., P.P.M.			Per Cent
	Dissolved	Suspended	Total	
Raw sewage	197	0	197	—
Biochemical				
Start	139	164	303	—
Adsorbed	58	—	—	29
Two hours	37	156	193	—
Adsorbed	160	—	—	81
Oxidized	—	—	110	36
Activated				
Start	186	69	255	—
Adsorbed	11	—	—	6
Two hours	54	67	121	—
Adsorbed	143	—	—	73
Oxidized	—	—	134	53

	Suspended Solids (p.p.m.) Start	Two Hours
Biochemical	1160	1200
Activated	490	550

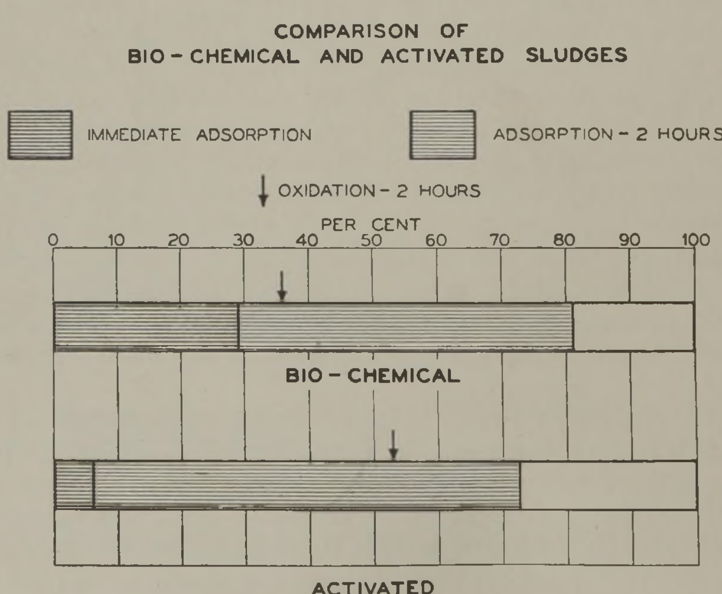

FIG. 4. Plotting of data of Table IV, last column.

These distinctions seem to be maintained throughout our work. The biochemical floc adsorbs more rapidly and more completely, and builds up faster, i.e., produces more conditioned sludge and does less oxidizing work. This will be illustrated further in what follows.

(4) *Conditioning of the Biochemical sludge requires a supply of normal sewage bacteria. It is then more readily accomplished, with shorter aeration periods, than in the case of activated sludge.*

TABLE V.—*Data of Continuous Experiment*
(*Average by Periods*)

Day	Biochemical				Activated				Raw Sewage
	Beginning		End		Beginning		End		
	Suspended Solids (p.p.m.)								
1	—		376		—		218		
2	—		916		—		196		
3	—		1052		—		380		
4– 6	—		987		—		119		
7–13	985		950		304		242		
14–18	1165		1208		492		552		
21–26	1045		1111		502		615		
28–31	1790		1870		1558		1642		
	5-Day B.O.D. (p.p.m.)								
	Sus.	Dis.	Sus.	Dis.	Sus.	Dis.	Sus.	Dis.	Total
1	—	—	119	26	—	—	99	26	110
2	—	—	122	13	—	—	69	26	80
3	—	—	159	6	—	—	82	18	97
4– 6	—	—	222	91+	—	—	59	139+	188
7–13	136	106	122	55	37	143	29	101	211
14–18	164	139	156	37	69	186	67	54	197
21–26	112	143	110	43	50	163	45	28	182
28–31	261	77	197	5	199	97	156	15	183

Notes to Tables:

The dissolved values are determined upon filtered samples.

Day: 1–6

One hour aeration, settling, decanting and refeeding, to condition the sludges. Sludge wasted from biochemical jar to maintain suspended solids at 1000 p.p.m. None wasted from activated. Screened domestic sewage fed for three days, then synthetic sewage until 28th day.

Day: 7–13

Aeration period, one hour on biochemical, two hours on activated.

Day: 10

Activated jar received 150 cc. thickened sludge from another experiment to speed up conditioning.

Day: 14–18:

Aeration period, two hours on each. This week is basis of Table IV.

Day: 21–26:

Aeration two hours on biochemical, three hours on activated.

Day: 28–31:

Aeration as above. Ten per cent screened domestic sewage added to feed.

TABLE VI.—*Summary of Computed Data*
(*Per Cent*)

Period, Days	Immediate Adsorption		Final		Oxidation	
	Bio.	Act.	Bio.	Act.	Bio.	Act.
7–13	50	32	74	52	27	28
14–18	29	6	81	73	36	53
21–26	21	10	76	85	40	66
28–31	58	47	97	92	40	42

The complete data upon the continuous experiment, a portion of which has just been referred to, are given in the following tables, with appended notes. The results given are averages for weekly periods of from 5 to 7 days each. The daily routine, as previously, consisted in three feedings each day, after settling and decanting the supernatant. This was done at intervals indicated in the notes, with continuous aeration during the periods and overnight and week-ends, if indicated. Sampling for analysis was done at the beginning, one or two minutes after feeding, and at the end of the third cycle each day.

Attention is called here to the rapid build-up of the biochemical sludge during the first three days (Table V) compared with the slow development of the activated, which had to be reinforced on the tenth day in order to get it up to a reasonable basis for comparison; also to the gradual loss of adsorptive capacity, despite a normal increase of solids, until domestic sewage was fed on the 28th day. The activated sludge did not suffer from lack of normal sewage bacteria but was in poor condition, as evidenced by poor settling qualities, until the last two periods when, with three hours aeration, it became well activated and worked comparable with the biochemical sludge, with two hours aeration. The more rapid immediate adsorption by the biochemical sludge is noticeable throughout.

In general we have noted a more uniform record, in the day-by-day results, for the biochemical system. The average values tabulated include data having a comparatively narrow range, as compared with those of the activated system. For example, during the fourth week the dissolved B.O.D. at the end of aeration was 43 and 28 p.p.m. respectively, suggesting a better effluent on the part of the activated system. We note, however, that the average of 43 p.p.m. comes from six values ranging from 21 to 53 p.p.m. whereas the average of 28 comes from four values ranging from 2 to 9, one of 52, and one of 98.

It may also be noted that a shorter period of aeration suffices to condition the biochemical sludge. The laboratory notes mention better settling throughout, both as to rapidity and as to completion of settling.

However, these points are not stressed here except in one connection. The endeavor has been to learn something of the fundamental nature of the Biochemical Process. One question naturally arose at the out-set: is biochemical sludge different from activated sludge? Our data throughout indicate an affirmative answer and our present purpose is merely to point out some of these differences.

SECTION II

Small Plant Operation

The experimental work thus far reported, done on a small scale, with laboratory glassware and largely with pure bacterial cultures and synthetic sewage, has led to certain conclusions which have been presented. Upon the basis of this work, two small plants were designed (Fig. 5), in order to compare in a more conventional manner, and especially under conditions of continuous operation, the relative performances of the biochemical and activated systems.

These plants were in continuous operation for a period of one year. They do not, of course, provide any useful information on the economics of operation of either system, especially as regards air quantities. We believe, however, that in view of the continuous record of operation, and of the careful control and strictly comparable basis maintained throughout, the results offer a reasonably accurate picture of the relative performance of the two systems.

Figure 1 shows the general layout of the two plants. The final clarifiers are the same size while the aeration tank for the activated sludge plant is twice the size of the biochemical. This provides a three-hour aeration period for the biochemical and a six-hour aeration period for the activated plant. The return sludge and waste of excess sludge from both plants are clearly indicated in the sketch. The manometers were calibrated so that a record of air used would be available. Two digesters of the same size were built. These are not shown in the sketch.

The raw sewage used was synthetic sewage inoculated with Dyckman Street sewage. Two hundred forty gallons were made up each day containing the following ingredients:

Peptone	250 grams
Beef extract	120 "
Urea	46 "
Domestic sewage	10 gallons

Operation.—The rate of sewage flow was maintained constant in each plant at five gallons per hour, 24 hours a day, seven days a week. The flow in the biochemical plant was increased to six gallons per hour April 15, 1941. The biochemical plant received a constant iron dosage of 5 p.p.m. Fe from a solution of ferric sulfate.

The return sludge in both plants varied between two and three gallons per hour. The lines became plugged if the rate was any lower. Thickened sludge was withdrawn once a day from each thickener and added to its respective digester. Supernatant liquor was withdrawn

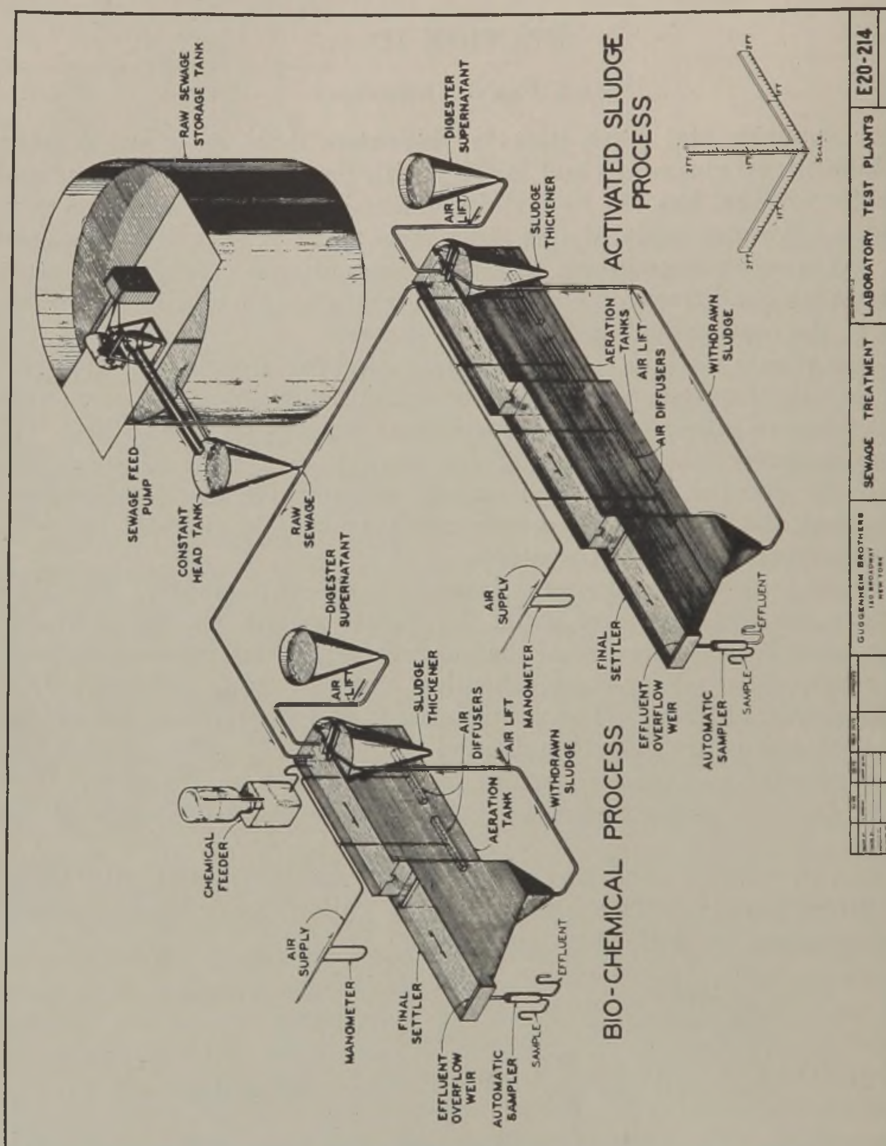

FIG. 5. Isometric Design of Experimental Plant.

once a day from the digesters and returned to its respective plant. Gas produced was collected, measured and recorded each day.

The automatic sampler for each effluent (Figure 1) consisted of a 1 in. diameter glass tube. This tube was closed at the bottom with a two-hole rubber stopper. Two adjustable siphons were connected to the bottom of the tube. The main flow of the effluent was discharged through one of the siphons and the sample through the other. The effluent discharge was a quarter-inch tubing and the sample discharge was one-eighth tubing. The sample discharge should be at right angles to the tube, otherwise if the flow through the tube should stop for any reason, the sampler would have to be re-adjusted. The sampler has the added advantage that a sample in proportion to the flow is obtained. It delivered about four gallons in 24 hours.

TABLE VII.—*Small Plant Operating Data. Monthly Averages*

Month	Biochemical			Activated		
	Air Cu. Ft./Gal.	Mixed Liquor (p.p.m.)		Air Cu. Ft./Gal.	Mixed Liquor (p.p.m.)	
		Susp. Solids	D.O.		Susp. Solids	D.O.
June, 1940	0.9	1140	0.0	2.2	840	0.0
July	2.6	1120	0.0	5.1	1200	0.0
August	5.2	800	1.9	12.0	560	2.6
Sept.	5.0	680	2.1	13.0	410	3.8
Oct.	4.7	530	3.5	11.0	290	5.0
Nov.	3.9	580	5.5	10.0	420	5.2
Dec.	3.9	630	4.1	10.0	530	4.6
January, 1941	3.9	830	3.9	10.0	650	4.4
February	3.9	820	4.0	10.0	550	5.4
March	3.6	690	3.0	10.0	490	3.8
April	3.2	1270	2.8	9.6	1060	3.6
May	3.7	1050	3.0	9.6	830	3.4
Average	2.8	850	2.8	9.4	630	3.5

Ferric sulfate applied throughout to biochemical system at rate of 5 p.p.m. of Fe.

Samples of raw sewage were taken for analyses each day, after the daily batch was made up. The mixed liquors in the aeration tanks were examined for suspended solids on composites made up of hourly samples during eight hours of each day; and for D.O. on a daily catch sample. The final effluents were sampled by the automatic samplers and represent a continuous collection over a twenty-four hour period.

The resulting data have been averaged by months and for the year for presentation in Table VII. The results include air consumption, suspended solids and D.O. maintained in the mixed liquors. Table VIII shows suspended solids and total and filtered B.O.D. on the raw sewage and the two effluents.

In addition to these analytical data on the final effluents we have similar daily analyses and monthly summaries for all the essential items. These have not varied significantly during the year and do not justify detailed presentation. We present, therefore, merely the yearly averages. The detailed sheets are available for study if desired.

These data require little if any discussion. The raw sewage was generally low in suspended solids. This resulted from the necessity of our using a standard synthetic sewage and detracts somewhat from the practical value of the data except for comparative purposes. After the air supply was adjusted to maintain a necessary residual D.O., the two systems operated about the same and the resulting effluents were strikingly alike.

The behavior and condition of the activated sludge throughout the year indicated that, regardless of air volume, a six-hour period of aeration was about the minimum. A few batch samples taken at the mid-point, representing three hours treatment, showed inferior purification.

These data support our previous conclusions in two respects. The iron-hydroxide sewage-bacteria system, here called the Bio-chemical System, does in fact simulate the activated sludge system as commonly understood. Both act by concentrating food within a sludge mass which forms a matrix for a heavy concentration of oxidizing bacteria. This in turn brings about a rapid rate of oxidation.

The formation of this matrix as a biological product of specific bacteria tends to exclude from the reaction many types of bacteria abun-

TABLE VIII.—*Small Plant Analytical Data. Monthly Averages. Parts per Million*

Month	Raw Sewage			Biochemical Effluent			Activated Sludge Effluent		
	Susp. Solids	B.O.D.		Susp. Solids	B.O.D.		Susp. Solids	B.O.D.	
		Total	Filt.		Total	Filt.		Total	Filt.
June, 1940	60	102	—	42	18	—	39	10	—
July	141	132	107	29	13	8	28	9	6
August	120	128	110	23	20	13	61	38	13
September	194	157	125	18	10	5	31	14	3
October	314	189	112	19	15	4	16	10	4
November	238	181	123	11	13	6	6	11	6
December	105	138	119	13	31	21	4	6	4
January, 1941	42	123	109	13	12	6	17	9	3
February	55	125	112	8	9	5	10	8	2
March	95	118	100	17	11	6	8	7	4
April	106	128	101	11	4	3	11	8	4
May	97	123	102	12	11	6	7	5	6
Average	130	137	111*	16	14	8*	20	12	5*

* Eleven months.

TABLE IX.—*Summary of Miscellaneous Analytical Data (Year Average)*

	Raw Sewage	Biochemical Effluent	Activated Effluent
Total solids: p.p.m.	477	188	193
Volatile p.p.m.	336	89	99
Ash p.p.m.	141	99	94
Nitrogen (Nov. & Dec. only)			
Ammoniacal p.p.m.	30	42	43
Organic p.p.m.	52	7	8

	Sludge Data	
Thickened Sludge to Digester		
Gallons per day	0.97	1.04
Volatile Solids, p.p.m.	10,300	7,800
Fixed Solids, p.p.m.	3,600	2,200
B.O.D., p.p.m.	2,700	2,100
Total N., p.p.m.	950	988
Supernatant Returned from Digester		
Gallons per day	0.76	0.95
pH	7.4	7.3
Volatile Solids, p.p.m.	2,300	1,300
Fixed Solids, p.p.m.	900	560
Suspended Solids, p.p.m.	800	630
B.O.D. Solids, p.p.m.	1,380	900
Total N., p.p.m.	650	390
Gas Produced (liters per day)	10.4	8.8
Digested Sludge Withdrawn (Gals.)	16	8.5
Volatile Solids, p.p.m.	17,000	15,000
Ash	18,000	11,000
Ash (per cent)	51	42

dantly present in sewage and capable of performing the same oxidizing function. On the other hand, formation of a floc, known to have adsorptive and clarifying powers, in the presence of the incoming sewage, concentrates large numbers of these oxidizing bacteria and produces and maintains a sludge system which, while of fundamentally different biological properties, differs in functional properties from the activated sludge only in its more rapid adsorption of soluble organic matter, indicated here by the lessened time required for conditioning, and in a somewhat greater build-up of organic sludge and consequent less total oxidation. This latter distinction is shown in the analyses of thickened sludge data in Table IX. On essentially the same total quantity of sewage treated, the biochemical system wasted to the sludge digesters 26 per cent more volatile solids, and 18 per cent more B.O.D., and produced 18 per cent more gas than the activated system.

We conclude from this series of comparative tests that the advantages of the biochemical sludge over the activated are evaluated with reasonable approximation by the shortened period of aeration found necessary.

SECTION III

Recapitulation

1. The Biochemical Process of sewage treatment, involving the addition of coagulant (ferric sulfate) to the primary tank effluent, and operating thereafter in the manner of the activated sludge process, including recirculation of return sludge, has been studied in the laboratory in order to learn as much as possible of the basic mechanism of this process.

2. It was found that the presence of iron in the quantities employed (5 to 10 p.p.m.) stimulated the growth of the common sewage organism, *Aer. aerogenes* and, after conditioning, increased the rate at which it reduced methylene blue (oxidized organic matter).

3. A pure culture of *aerogenes,* fed intermittently with synthetic sewage and treated with ferric sulfate, developed an active sludge mass capable of performing the two chief functions of activated sludge, namely rapid adsorption of soluble organic matter followed by oxidation of soluble and insoluble solids at a much higher rate than that normally associated with that organism in the B.O.D. reaction.

4. In the presence of a mixture of activated sludge in pure culture and the iron floc, not activated, adsorption goes largely to the iron floc to the extent that the activated sludge is prevented from performing its ordinary oxidizing function.

5. Given a continuous supply of normal sewage bacteria, the conditioning of the biochemical sludge is rapid, two or three days being adequate to bring it to equilibrium with a sewage of 200 p.p.m. B.O.D. (all in solution) and to build up a mixed liquor of 1,000 p.p.m. suspended solids.

6. This biochemical sludge will, therefore, become established in preference to the activated sludge and will tend to restrain the development of the latter under the designated operating conditions. Its ability to adsorb more rapidly, together with the coagulating action of the freshly applied chemical, gives it an advantage over the slower acting sludge, which is reflected in practice in a reduced time requirement for aeration and consequent indicated economy in tank volume and in air.

Discussion

By Harry W. Gehm

Sewage Experiment Station, New Brunswick, N. J.

Discussion of Professor Phelps's work is rather difficult due to the fact that it raises so many debatable questions in one's mind concerning the actual mechanism of the so-called "Bio-Chemical Process." The writer has elected to follow through the several postulates evolved and to comment upon each in turn.

The first of these was the statement that ferric sulfate stimulates the growth of certain bacteria, thus increasing the rate of bio-chemical oxidation. This supposition is supported by convincing experiments, made on pure broth cultures of an organism which is present to some extent in sewage. The question as to whether the same stimulation occurs in sewage, however, is left unanswered.

In 1928, Buswell (1) was able to demonstrate that pure cultures of aerobic organisms could be made to perform most of the functions of activated sludge. His work has since been enlarged upon by several investigators. Thus, the statement that the combination of iron floc and *B. aerogenes* in pure culture may be made to simulate activated sludge is not a surprising revelation. From the experiments the authors present, we come to the following conclusions:

1. Iron is a good coagulant
2. Certain bacteria may cause clarification
3. The combination of chemical coagulation and biological clarification may be novel.

The first two conclusions are rather well-known, the third is perhaps a question of interpretation.

Evidence is presented to show that the absorptive power of ferric hydroxide floc is greater than that of normal activated sludge, equally well conditioned, and in the presence of sewage bacteria, will eventually eliminate the predominating flora of the latter. The data are undoubtedly indicative that this phenomenon takes place, although not entirely convincing. No actual data showing the absence of zoogleal organisms in the "Bio-Chemical floc" are presented. The explanation offered for the elimination of the activated sludge flora is subject to different interpretation. Are these organisms starved through selective absorption or because the iron combines with some of the organic matter, making it unavailable as food for them? The authors believe to have established that adsorption of dissolved material takes place faster in biochemical than in activated sludge, although in the experiments presented, higher rates of this reaction seem incidental. Practically the same amount was absorbed and indeed partly oxidized in two hours by the activated sludge, operating with only about 500 p.p.m. of solids in the mixed liquor against over 1100 for the Bio-Chemical sludge.

The pilot plant experiments, in which synthetic sewage was treated, were of decided interest. It is unfortunate that the comparisons of the "Bio-Chemical" with activated sludge processes were made with so low a suspended solids concentration in the mixed liquor of the latter. The yearly average was only 630 p.p.m. for the activated process while the concentration of Bio-Chemical sludge averaged 25 per cent higher. If a straight-line adsorption function is assumed, this would account for 25 per cent additional adsorption or a corresponding reduction in time. It has been demonstrated repeatedly that activated sludge operation at so low a concentration of solids in the aeration tanks is critical, to say the least, and in this case may have accounted for some of the results obtained. The data would have been much more convincing if standard activated sludge practice had been adhered to in operation of the control experiments.

Dr. Mohlman in a recent editorial in the "Sewage Works Journal" pointed out instances where the activated sludge process is employed and iron is present in the sewage in larger quantities than are added in the Bio-Chemical Process. Granting that the iron present is not in the form of an active coagulant, as is the iron added in the process, but probably as hydroxides, it should affect the flora of the sludge, if the statement that iron hydroxide is responsible for a change in the flora is correct. This does not appear to be the case, particularly at Chicago, where I understand rather normal activated sludge is obtained with sewage containing very high concentrations of iron.

The possible elimination of aeration to oxidize a sizeable amount of the sewage organic matter, so necessary to the activated sludge process, is of economic importance. It is much cheaper to destroy this material in the digester, as no power is required, valuable gas is recovered and plant construction cost is lowered. In the "Bio-Chemical" process some of these savings are absorbed by the necessary use of a coagulant. However, this process is an interesting step in the direction of shortening the time required for a biological process and represents an effort toward advancing the activated sludge type of process to keep pace with the recent rapid advances in trickling filters, and to widen the scope of chemical treatment.

Discussion

By Gordon M. Fair

Harvard Graduate School of Engineering, Cambridge, Mass.

Professor Phelps has accomplished to an admirable degree and in a uniquely happy form his avowed purpose of exploring the fundamental principles upon which the operation of the Guggenheim "Biochemical Process" depends. In doing so, he has rendered valuable service to the profession and has placed the process among the rationally explainable methods of sewage treatment.

Working with pure cultures of zoogleal organisms and synthetic sewage, Professor Phelps has shown that iron floc is a useful "surface-forming" material which promotes growth of bacteria and with it of respiration. This is in full accordance with established principles of sewage treatment.

In connection with Proposition 3, it has been the experience of the writer's laboratory that sludge that is fed but twice a day cannot be fairly classified as a "normal activated sludge." It is in fact a starved sludge of limited adsorptive power. Lack of suspended matter in the synthetic sewage employed works to the further disadvantage of the sludge to which no iron is added. The tests performed with this sludge do indicate, however, that the biochemical sludge appears to be more rugged and more readily generated than activated sludge. This property may establish the value of the Guggenheim process particularly in the treatment of industrial wastes.

LOAD DISTRIBUTION IN THE ACTIVATED SLUDGE PROCESS *

By J. E. McKee and Gordon M. Fair

Harvard Graduate School of Engineering, Cambridge, Mass.

In the activated sludge process, as conventionally conducted, the entire load of sewage matters is impressed upon the returned sludge, or active contact medium, in a single dose. Although the nature of the individual links in the chain of purifying events that is thereby uncoiled is, as yet, but vaguely known, it is generally thought that two broad classes of happenings can be distinguished: (1) a physical process of adsorption and flocculation, which is instituted immediately, proceeds rapidly, and decreases in rate as the suspended, colloidal, and dissolved substances are removed from the sewage to the sludge flocs and as the contact surfaces become covered with these substances, or otherwise inactivated; and (2) a biological process of food consumption for energy production and cell synthesis which, likewise, is instituted immediately but proceeds more slowly and, after a probable initial acceleration, is retarded gradually as the pabulum contained in the sewage is consumed or changed in character by the hosts of bacteria and other primitive organisms that flourish in activated sludge and, by their foraging activities, regenerate the contact surfaces of the sludge flocs. The physical process of adsorption and flocculation brings about a *change in state* of the pollutional substances by removing them from the flowing sewage and converting or attaching them to flocs. It appears to be confined largely to the first hour or so of conventional operation. The associated biological process of food utilization and sludge regeneration, on the other hand, brings about a *change in structure and composition* of the flocculated substances and is known to require many hours to accomplish this change.

In 1937 the senior author (G. M. Fair) advanced the hypothesis that incremental addition of sewage to returned activated sludge along the line of flow would help to equalize the physical and biological phases of the activated sludge process and thereby increase its efficiency, or economy. At about the same time, this hypothesis found independent expression in the provision by Richard H. Gould of means for introducing sewage at three points along the aeration units of the Tallmans Island Activated Sludge Plant of New York City. Gould (1) has described the design of these units as follows: "These tanks incorporate a principle, original, it is believed, with the author, whereby the sewage can be introduced in regulated amounts at multiple points throughout the course of the flow of the returned activated sludge through the tank." To Gould, therefore, belongs the credit of prior publication and practical

* Presented at the Second Annual Convention of the Federation of Sewage Works Associations, New York City, October 9, 1941.

application of the fundamental concepts of the subject matter of this paper. Preliminary experiments on load distribution were performed by the authors and their associates in 1938, but the studies reported in this paper were not begun until 1939 when satisfactory experimental equipment to test the new process had been made available.

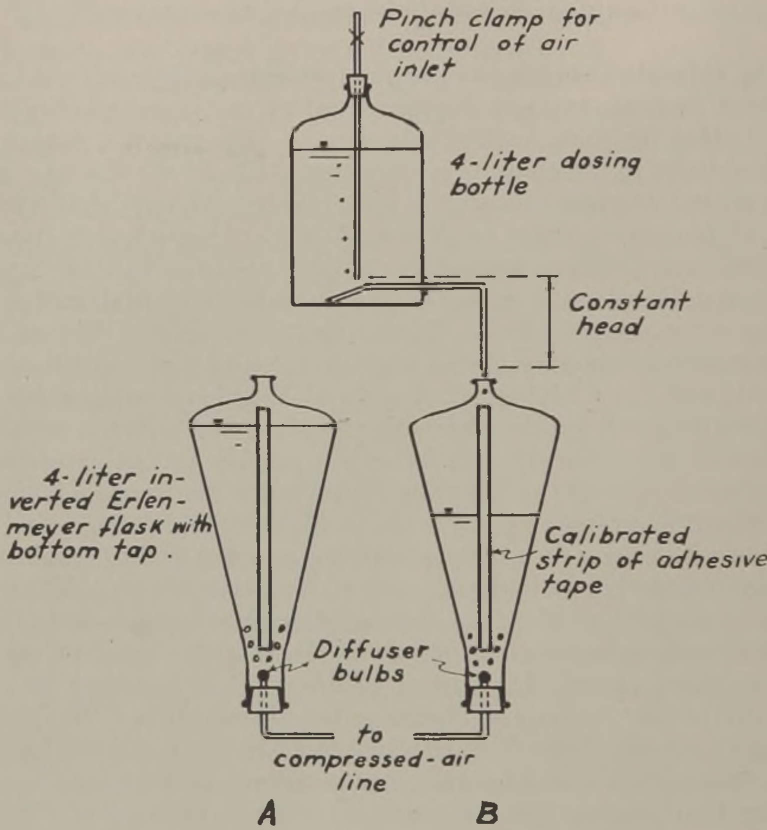

FIG. 1.—Aerating flasks used in the study of conventional and incremental dosing. The activated sludge in flask *A* received a single dose of sewage. To the sludge in flask *B* sewage was added gradually over a period of time.

It is the purpose of this paper (1) to show that it is possible to maintain the activated sludge process of sewage treatment by adding sewage gradually to returned sludge instead of in a single dose, and (2) to suggest that this modified process gives promise of establishing certain economies in plant design and operation, greater flexibility in the control of effected treatment, and reduced risk to the sludge by the sudden imposition of batches of strong or toxic industrial wastes. Gould has called the method of operation incorporated at Tallmans Island *step-aeration;* the authors prefer to identify the principle involved as *distributed loading, multiple-point dosing,* or *incremental dosing.* The modification must not be confused with the abortive attempt at stage treatment in which aeration units were placed in series and sludge was recirculated within each stage or distributed between the stages; nor must it be confused with *tapered aeration* in which the air supply is reduced in step with the decreasing oxygen requirements of the flowing sewage.

Experimental Equipment.—The apparatus employed in the comparative study of single and multiple-point dosing is outlined in Fig. 1. Its operation was straightforward. A batch of activated sludge, occupying a predetermined portion of the total volume, was placed in each flask. To one flask (A) the full amount of sewage to be treated was added in a single dose; to the other flask (B), sewage was added at a rate such as to reach the full amount during a certain portion of the

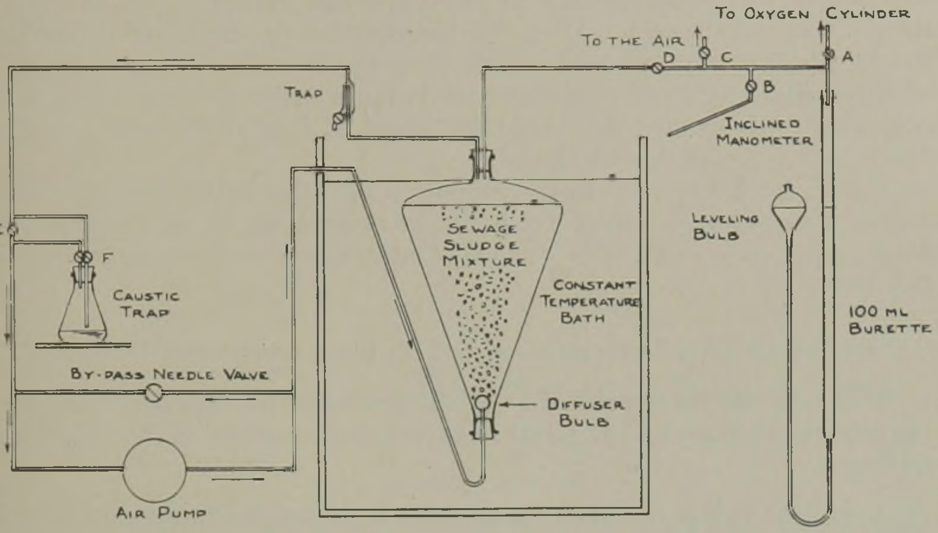

FIG. 2.—Respirometer. The sewage, sludge, or mixture is aerated in a closed circuit from which CO_2 is removed by a caustic trap and in which oxygen is replenished from a burette, the circulating air being kept at nearly constant pressure and temperature.

aeration period. Both vessels were supplied with air for the desired length of time. The air was then shut off, the sludge allowed to settle, the supernatant decanted, and the necessary amount of sludge wasted. Sewage was thereupon added to the flasks as before, and the cycle of operations was repeated as often as was found necessary to establish an activated sludge that was characteristic of the sewage, the method of aeration and, most important, the method of dosing. The performance of the two treatment processes was measured in terms of the reduction in the B.O.D. of the sewage, the specific volume * and content of volatile matter of the sludge, and the rate of oxygen demand of the mixture of sewage and sludge. The microscopic appearance of the activated floc was also observed. To supply sewage at a constant rate to Flask B, a device suggested by Wilson and McLachlan (2) was employed, a pinch clamp being substituted for the capillary air inlet in order to secure more flexible control of discharge.

* Generally called the Mohlman sludge index.

Rate of oxygen demand was measured in a respirometer, Fig. 2, that has been described before (3). Flasks, such as those shown in Fig. 1, were incorporated in the recirculation system of this device, and tests were run not only on the activated sludges that were built up in the main group of experiments but, preliminary to this undertaking, also on sewage, sludge, and mixtures of the two for the purpose of differentiating between the oxygen demand due to oxygen undersaturation of sewage and sludge and that due to respiration or metabolism of the activating organisms. The respirometer, furthermore, made possible a direct visualization of the relative reaction of activated sludges to single- and multiple-point dosing by tracing the curves of oxygen demand of a given sludge that was being dosed with sewage under different sets of conditions. The respirometer (Fig. 2), therefore, was employed primarily to indicate the effect of load distribution upon rate of oxygen demand within a single cycle of operation, while the equipment shown in Fig. 1 was used to determine the long-time effect of load distribution on the condition of the sludge produced.

Fresh, settled sewage was available in the laboratory, and activated sludge was obtained either from the treatment works at Leominster, Mass., or from a small plant that was maintained in the laboratory for this purpose.

Effect of Load Distribution on the Rate of Oxygen Demand

When sewage and returned activated sludge are aerated together, the oxygen used up by the mixture serves one or more of the following purposes:

1. It goes into solution in an attempt to saturate sewage and sludge with oxygen.
2. It is used from solution to satisfy the immediate or chemical oxygen demand of sewage and sludge, if such demand exists.
3. It is utilized from solution to meet the respiratory or metabolic requirements of the purifying organisms.

In the rate curve of oxygen demand, traced during a cycle of aeration, these three different activities overlap and create an initial peak rate of oxygen demand from which subsequent rates fall away to a slowly decreasing base value. Since it was the purpose of the present study to modify the activated sludge process in such manner as to establish for each unit of contact material a nearly uniform rate of respiration and with it of oxygen demand—in place of the tapering demand of the conventional process—it was necessary to identify in the tests, or to remove from them, the saturation and chemical demands that mask the true magnitudes of respiration.

Oxygen Demand of Stale Sewage.—Duplicate measurements of the rate of oxygen demand at 18° C. of a stale sewage (0 p.p.m. of dissolved oxygen) containing 237 p.p.m. of suspended solids, and possessing a 5-day, 20° C., B.O.D. of 234 p.p.m., are shown in Fig. 3. It is seen that about 40 min. were required to bring the dissolved oxygen content of the sewage into equilibrium with the gaseous oxygen carried by the recirculating air. Although the sewage was only moderately strong and had been standing for but one hour, its initial rate of oxygen demand is indicated to have been between 25 and 40 p.p.m. per hour during the first ten minutes of aeration. It seems quite possible, therefore, that strong sewage may reach a saturation demand of 100 p.p.m. per hour during a similar period of time.

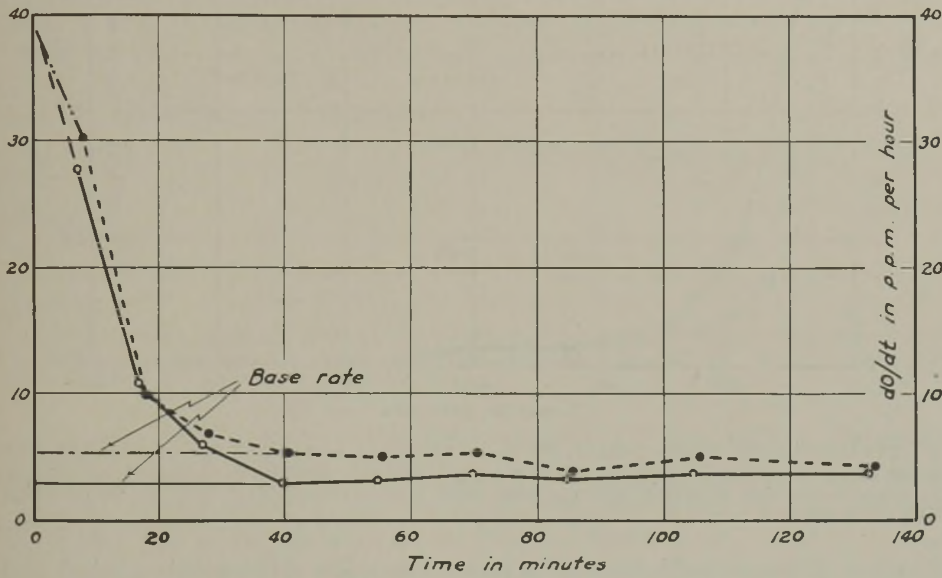

FIG. 3.—Rate of oxygen demand, dO/dt, at 18° C., of duplicate samples of stale sewage containing 0 p.p.m. of dissolved oxygen and 237 p.p.m. of suspended solids, and exerting a 5-day, 20° C., B.O.D. of 234 p.p.m.

The area under the two curves of Fig. 3, up to the 40th minute and above the indicated base rates, establishes the initial oxygen consumption of the sewage at a value of about 9.0 p.p.m. (solid curve) and 8.5 p.p.m. (dotted curve) respectively. According to Moore (4), this is approximately equal to the dissolved oxygen saturation value of sewage at 18° C. (9.0 p.p.m.). It appears, therefore, that the sewage tested had no chemical demand unless it was satisfied in the first few minutes of the respirometer run, *i.e.* before its effect could be registered.

Oxygen Demand of Stale Mixtures of Sewage and Activated Sludge. —The rates of oxygen demand at 22° C. of mixtures of sewage and activated sludge that had been allowed to stand without aeration for one hour before being mixed and had then been inactivated by the addition of 10 ml. of a 10-per cent solution of copper sulfate to 600 ml. of the sludge are shown in Fig. 4. Sample A contained 1300 p.p.m. of suspended solids of which 88.0 per cent were volatile. The corresponding values for Sample B were 1150 p.p.m. and 85.6 per cent. About 40 minutes are again seen to have elapsed before equilibrium was reached.

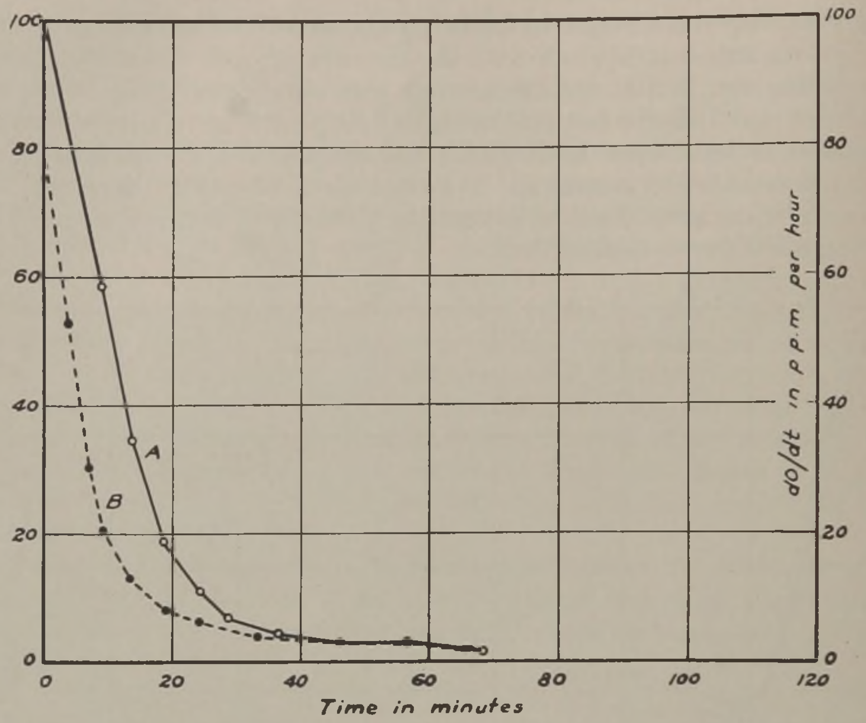

FIG. 4.—Rate of oxygen demand, dO/dt, at 22° C. of mixtures of stale sewage and activated sludge that had been inactivated by copper sulfate. Sample *A* contained 1300 p.p.m. of suspended solids of which 88.0 per cent were volatile; Sample *B* 1150 p.p.m. of which 85.6 per cent were volatile.

Sample A consumed about 20 p.p.m. of oxygen during this period and Sample B about 10 p.p.m. Mixed liquor at these concentrations of suspended matter has a dissolved oxygen saturation value of 8.0 p.p.m. at 22° C. (4). This leaves an oxygen demand in excess of saturation requirements equal to $(20 - 8) = 12$ p.p.m. for Sample A and $(10 - 8) = 2$ p.p.m. for Sample B. The fact that Sample A contained a very high percentage of volatile matter is an indication of an overloaded sludge that decomposes quickly. This possibility, together with the difference in weight of suspended solids, may explain the difference in the initial and excess oxygen demands of the two samples.

Effect of Preaeration on the Oxygen Demand of Stale Mixtures of Sewage and Sludge.—It follows from observations such as these that it should be possible to lower the peak demand of mixtures of sewage and activated sludge appreciably by preaeration of the two components. To what extent this can be done must depend upon circumstances. An example is given in Fig. 5 in which the curves trace the rates of oxygen demand of two mixtures of sewage and activated sludge, one of which, as shown by the upper curve (A), had been mixed after the sewage and the sludge had been allowed to become stale by standing unaerated for an hour, whereas the other, as shown by the lower curve (B), had been mixed after the sewage and the sludge had been aerated

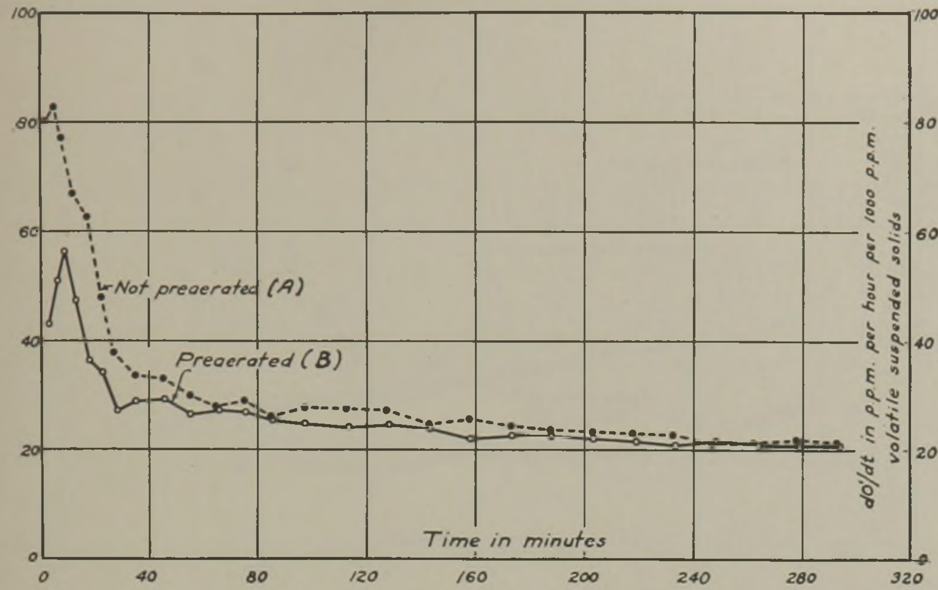

FIG. 5.—Rate of oxygen demand, dO'/dt, at 19° C. of mixtures of (1) stale and (2) preaerated sewage and activated sludge. The sewage had a 5-day, 20° C., B.O.D. of 336 p.p.m. and contained 440 p.p.m. of suspended solids.

separately for an hour. The peak is seen to have been reduced by about a third, the rate of demand being expressed, for purposes of comparison, in parts per million per hour per 1000 p.p.m. of volatile suspended solids in the mixture at the start of the test.

Oxygen Demand in Incremental Dosing.—It is obvious from Fig. 5 that preaeration alone does not eliminate the peak nor the subsequent slower decline in the rate of demand for oxygen by mixtures of sewage and activated sludge in which all of the sewage is added at one time to the contact medium (single-point, or conventional, dosing). The pattern of the curve is profoundly modified, however, by adding the sewage gradually (multiple-point, or incremental, dosing), as demonstrated in Figs. 6 and 7.

The observations plotted in Fig. 6 were obtained in the following manner. To three 600-ml. samples of an activated sludge were added: (*A*) a single three-liter dose of sewage, (*B*) six 500-ml. doses of this sewage at half-hourly intervals from the start, and (*C*) a single dose of three liters of tap water. Rates of oxygen demand were measured in the respirometer and are plotted as parts per million per hour per 1000 p.p.m. of volatile suspended solids in the mixture. This method of expressing the rate of oxygen demand was chosen because it reflects the oxygen demand of the individual active agent or unit—bacterium or sludge floc—regardless of the system of dosing. The sludge had been preaerated, but the sewage had not. This accounts for the high rates of oxygen consumption observed immediately after dosage, whatever the sample. Incremental dosing (*B*), however, is seen to straddle a

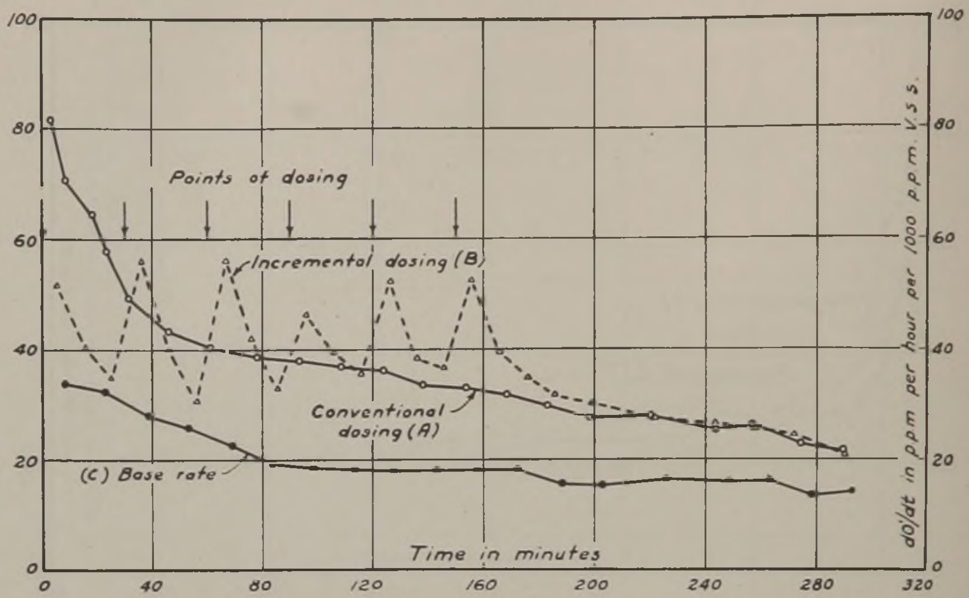

FIG. 6.—Rate of oxygen demand, dO'/dt, at 23° C., of 600 ml. of activated sludge receiving (*A*) a single dose of three liters of sewage, (*B*) six doses of 500 ml. of sewage at half-hourly intervals, and (*C*) a single dose of three liters of tap water. The sewage had a 5-day, 20° C., B.O.D. of 232 p.p.m. and contained 290 p.p.m. of suspended solids; 86.5 per cent of the solids suspended in the mixture were volatile. Sample *A* contained 717 p.p.m. of volatile suspended solids; Sample *C* contained 475 p.p.m. The sewage was not preaerated, but the sludge was.

rate more or less parallel to the base rate of the sludge until further addition of sewage to the sample was stopped after 2½ hours in order to produce substantially the same effluent, in terms of oxygen requirements, after 5 hours of aeration by incremental dosing (*B*) as was obtained in 5 hours by conventional dosing (*A*). That this result was accomplished is seen (1) by the coincidence of curves *A* and *B* about an hour after the last incremental dose and (2) by the fact that the final rate of oxygen demand of both samples reached a value close to the base rate of the sludge (*C*). That the sludge employed in this experiment was overloaded is made evident by the rapid drop in rate of oxygen demand observed during the first hour of aeration and by the convex shape of the curve of demand. Had the sludge been undersaturated, rather than overloaded, the curve would have been concave. Beyond the first hour of aeration, *autolysis* (self-digestion) of the sludge in satisfying the hunger of the surviving active organisms appears to have gradually reduced the oxygen demand of the sludge still further. The high initial concentration of volatile suspended solids associated with incremental dosing creates an oxygen demand, which, although less per unit weight of solids, is appreciably higher per unit volume of mixture than that of the sample that is dosed in the conventional manner. But this over-all rate is not as great as that observed in the reaeration of sludge, and the total oxygen consumption in any given time lags behind that of the conventional mixture.

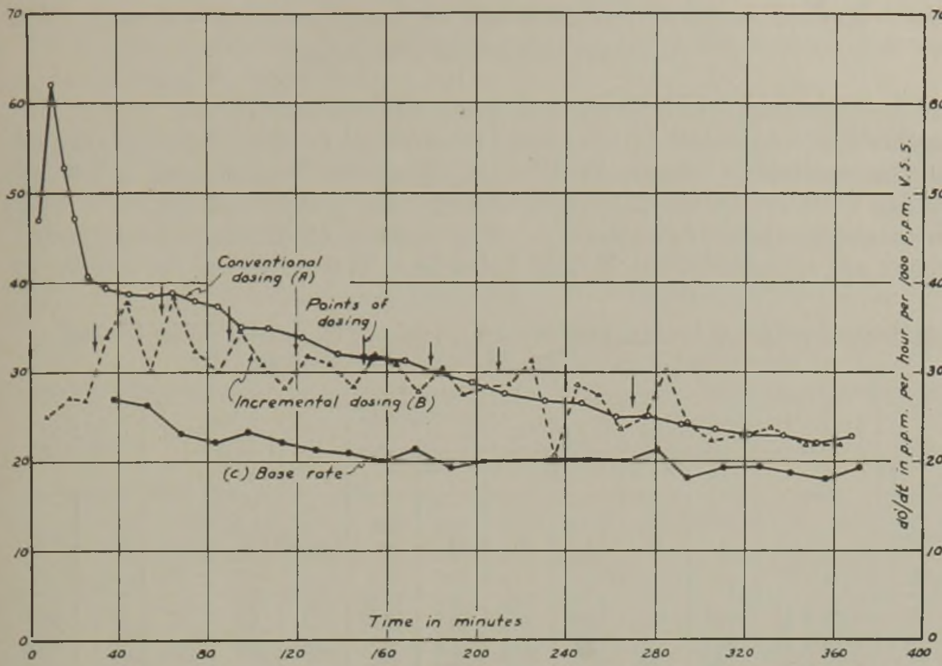

FIG. 7.—Rate of oxygen demand, dO'/dt, at 22.5° C. of one liter of activated sludge receiving (A) a single dose of three liters of sewage, (B) ten doses of 300 ml. of sewage at half-hourly intervals, and (C) a single dose of three liters of tap water. The sewage had a 5-day, 20° C., B.O.D. of 292 p.p.m. and contained 427 p.p.m. of suspended solids; 87.0 per cent of the solids suspended in the mixtures were volatile. Sample A contained 793 p.p.m. of volatile suspended solids after receiving its full dose of sewage; Sample C contained 493 p.p.m. Sewage and sludge were preaerated.

The observations plotted in Fig. 7 were similarly derived, but sewage increments were ten in number, extended over 4½ hours, and reduced to 300 ml. in volume. Observations were continued just beyond six hours. Preaeration helped to cut down the initial peak rates of all samples; otherwise the picture remained much the same with the exception that the food content of the first incremental dose of sewage (300 ml. of sewage added to 600 ml. of sludge) appears to have been insufficient to arrest autolysis of the sludge, as seen by the fact that the first three points of Curve B are no higher than those of the base rate (C).

Tests such as these, however, are not proof, in themselves, of the practicability of incremental dosing, because they were conducted, for direct comparisons, with a sludge that had been activated in the conventional manner and that was exposed to distributed loading during but one cycle of its life. Evidence is required, therefore, also of the ability of the modified process to maintain itself through a sufficient number of cycles to produce an autogenous activated sludge that will purify sewage as satisfactorily as does the conventional system of operation.

Effect of Load Distribution on the Condition of the Activated Sludge Produced

As previously indicated, activated sludges indigenous to the two methods of operation (single and incremental dosage) were developed in the equipment shown in Fig. 1. Duplicate samples of activated sludge were fed thrice daily with sewage over a sufficient length of time to establish their individuality. The results obtained in two experiments are summarized in Tables I and II. The ability of the two types

Table I.—*Effect of Load Distribution on the Condition of the Activated Sludge Produced*
Experiment No. 1. Activated Sludge from Leominster, Mass.

Date	Time	Suspended Solids in Mixed Liquor, P.P.M.		Specific Volume of Sludge*		Per Cent Volatile Matter in the Suspended Solids		B.O.D., 5-day, 20° C., P.P.M.			Per Cent B.O.D. Reduction	
January 1941		A	B	A	B	A	B	Sewage	Effluent A	Effluent B	A	B
14	8:20 P.M.	927	851	206	265	86.9	88.4	171	21	23	87.7	86.5
15	8:30 A.M.	897	856	210	259	88.3	86.5	202	20	30	90.1	85.1
	3:30 P.M.	988	982	188	242	87.3	86.3	—	—	—	—	—
	8:30 P.M.	1059	1107	170	206	88.1	87.0	—	—	—	—	—
16	8:00 A.M.	1033	1061	168	185	86.0	—	198	15	21	92.5	89.4
	3:10 P.M.	937	1085	177	166	87.2	87.3	—	—	—	—	—
	9:30 P.M.	1104	1053	152	210	86.6	87.3	—	—	—	—	—
17	8:00 A.M.	1225	1043	134	185	84.7	85.3	248	20	25	92.0	90.0
	2:40 P.M.	1332	1137	122	168	85.2	86.9	—	—	—	—	—
	8:35 P.M.	1363	1342	132	167	83.4	84.1	—	—	—	—	—
18	9:00 A.M.	1413	1332	125	150	84.2	84.9	185	14	15	92.5	92.0
	2:50 P.M.	1204	1188	109	127	83.0	84.4	—	—	—	—	—
	8:30 P.M.	1148	1119	117	143	84.6	83.7	—	—	—	—	—
19	10:40 A.M.	1162	1003	110	136	82.8	84.2	169	21	30	87.5	82.3
	7:10 P.M.	1222	977	107	140	82.8	84.0	—	—	—	—	—
20	8:40 A.M.	1287	1047	98	123	82.5	83.3	270	—	—	—	—
21	4:50 P.M.	1317	1190	102	117	83.5	83.9	262	25	15	90.5	94.4

A. Conventional sample, or control; each sewage dose administered in a single batch.
B. Incremental sample; sewage load distributed over 3 to 4 hours.
* Mohlman's sludge index (5).

of sludge to purify the sewage added is here expressed in terms of the 5-day, 20° C., B.O.D. of the influent and effluent sewage and the resulting percentage reduction in B.O.D. Sludge condition is indicated by this B.O.D. reduction but also by the variation in the specific volume * of the sludge—a measure of its settleability—and by the percentage of volatile matter in the suspended solids, a measure of the capacity of the sludge to maintain and regenerate itself.

Removal of B.O.D.—As seen in Tables I and II, incremental dosing (B) produced substantially as good an effluent as conventional dosing

* (5) milliliters occupied by one gram of sludge.

(A) in Experiment No. 1 and a substantially better one in Experiment No. 2, once the sludge had adjusted itself to the sewage employed and to the method of operation.

Rate of Respiration.—After seven days of feeding, the rates of respiration of the two samples were measured. Curves similar to those shown in Figs. 6 and 7 were obtained. From this it would appear that

TABLE II.—*Effect of Load Distribution on the Condition of the Activated Sludge Produced*
Experiment No. 2. Activated Sludge from Laboratory Plant

Date 1941	Time	Suspended Solids in Mixed Liquor, P.P.M.		Specific Volume of Sludge*		Per Cent Volatile Matter in the Suspended Solids		B.O.D., 5-day, 20° C., P.P.M.			Per Cent B.O.D. Reduction	
		A	B	A	B	A	B	Sewage	Effluent A	Effluent B	A	B
Jan. 31	3:00 P.M.	789	776	199	202	84.8	84.2	172	20	20	88.4	88.4
	9:10 A.M.	883	868	197	257	84.2	84.4	—	—	—	—	—
Feb. 1	8:40 P.M.	871	844	185	226	86.0	85.7	162	3	4	98.0	97.5
	3:10 P.M.	983	952	172	216	84.1	83.9	—	—	—	—	—
	9:00 P.M.	962	1017	185	240	84.8	84.5	—	—	—	—	—
Feb. 2	9:35 A.M.	986	929	191	262	86.9	84.6	189	15	29	92.0	84.6
	3:00 P.M.	1235	1326	150	216	85.6	84.8	—	—	—	—	—
	8:30 P.M.	905	905	173	300	84.8	85.1	—	—	—	—	—
Feb. 3	8:40 A.M.	1043	917	174	359	84.5	83.7	167	25	16	85.0	90.5
	3:10 P.M.	1013	782	147	296	86.6	85.5	—	—	—	—	—
	9:10 P.M.	1071	835	157	327	86.4	86.5	—	—	—	—	—
Feb. 4	8:40 A.M.	1113	816	137	273	86.8	86.8	120	37	14	69.1	88.3
	3:10 P.M.	1176	986	148	284	84.4	83.7	—	—	—	—	—
	9:00 P.M.	1251	982	125	291	85.9	85.8	—	—	—	—	—
Feb. 5	8:20 A.M.	1171	926	144	293	86.0	85.6	150	52	45	65.4	70.0
	4:50 P.M.	1421	1007	127	278	85.1	84.2	—	—	—	—	—
	9:10 P.M.	1321	1038	131	303	84.5	83.6	—	—	—	—	—
Feb. 6	8:50 P.M.	1005	1056	139	325	86.1	84.4	197	12	3	93.9	98.4
Feb. 7	3:50 P.M.	1040	1043	137	383	87.0	86.7	145	16	3	89.0	98.0
Feb. 8	2:30 P.M.	1306	957	109	359	85.0	84.8	78	13	3	83.4	96.1
Feb. 9	3:20 P.M.	1545	1093	102	288	82.0	80.6	168	12	2	92.8	98.8
Feb. 10	3:10 P.M.	1293	882	93	230	81.7	81.4	194	61	12	68.5	93.9
Feb. 11	8:50 A.M.	1534	1114	98	221	80.5	82.1	—	—	—	—	—

A. Conventional sample, or control; each sewage dose administered in a single batch.
B. Incremental sample; sewage load distributed over 3 to 4 hours.
* Mohlman's sludge index (5).

the metabolic activity of the sludge, as well as its clarifying power, was not impaired by load distribution.

Specific Volume.—In Experiment 1, the specific volume of both samples decreased progressively during the test, the incremental sample (B) lagging somewhat behind the conventional one (A). This decrease was accompanied by a small, but significant, reduction in the percentage of volatile matter in the suspended solids. This parallelism has been noted before (6). In Experiment 2, the specific volume of the incre-

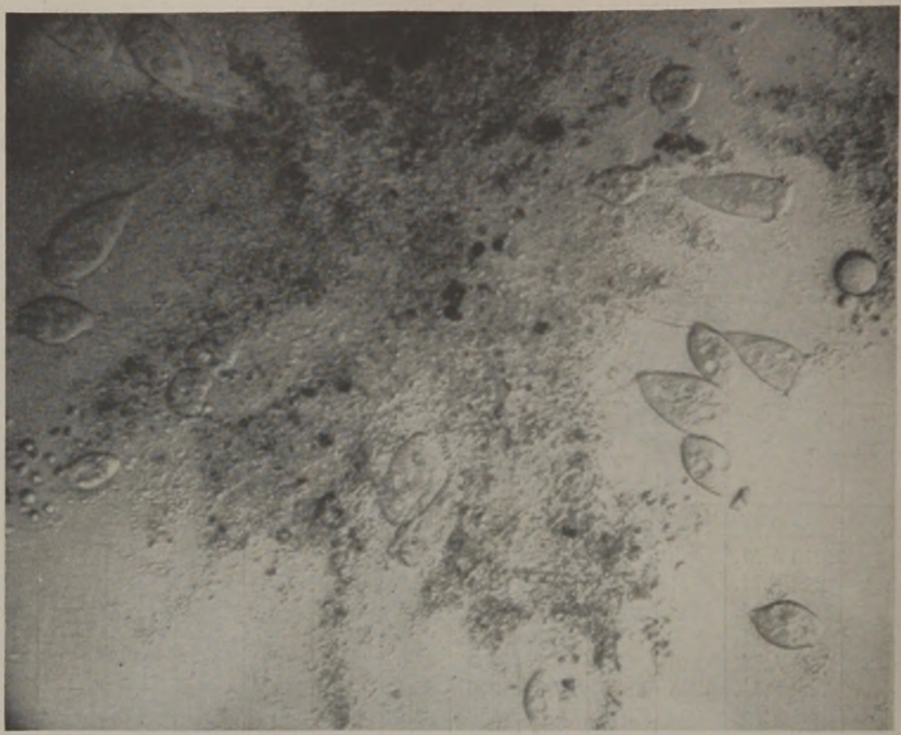

FIG. 8.—Leominster, Mass., activated sludge used at the start of Experiment 1. Note the large number of long-stalked, free-moving, colonial ciliates

mental sample (B) almost doubled before it returned to nearly its original value. The specific volume of the conventional sample (A), on the other hand, declined steadily to almost half its initial magnitude. Associated with low specific volume in this sample was "blanket rising" of the sludge when the mixture was allowed to settle for more than an hour.

It should be noted, in passing, that high specific volumes do not necessarily mean unsatisfactory operation and may not be associated with a deterioration in the quality of the effluent produced, as shown by the B.O.D. values, nor with an overloading of the sludge, as indicated by the percentage of volatile matter in the sludge. The decrease in the specific volume of the sludge in the conventionally dosed samples (A) in both experiments and the accompanying reduction in percentage of volatile matter in the suspended solids, are signs that these sludges were being overaerated or underfed.

Microscopic Appearance. Microscopic examinations of the samples were made about every three days. Some concept of the observed biological associations can be gained from Figs. 8 to 13. Experiment No. 1 was started with activated sludge brought into the laboratory from the municipal plant at Leominster, Mass. A photomicrograph of this sludge is shown in Fig. 8. Stalked ciliates, particularly *Vorticella,* are seen to have abounded. Although the specific volume of the sludge,

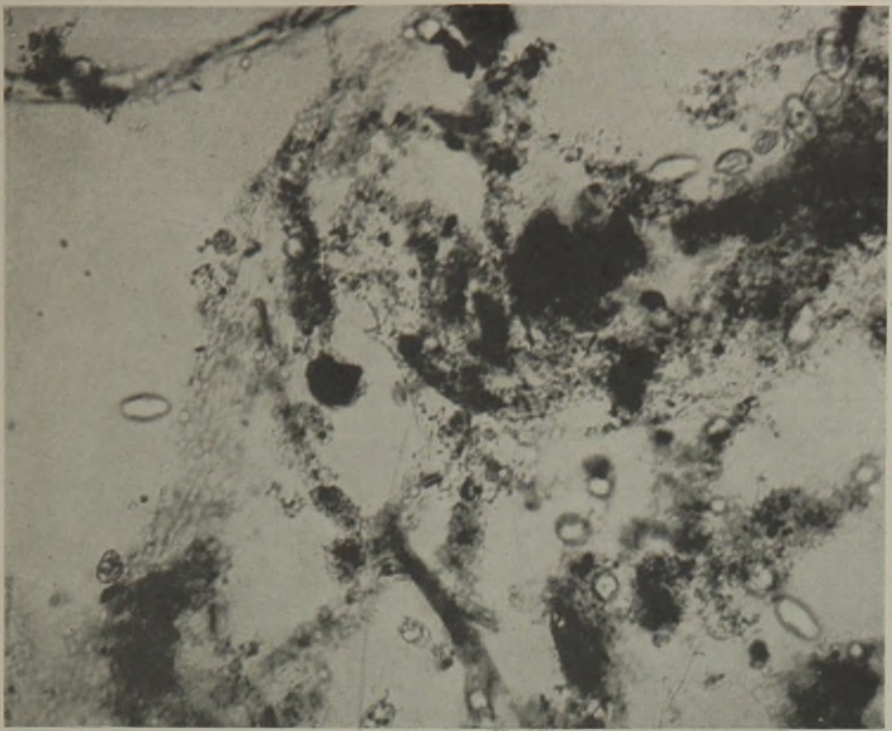

FIG. 9.—Changes brought about in Leominster, Mass., activated sludge by seven days of conventional dosing with Cambridge sewage in Sample *A* of Experiment 1. Note the absence of larger motile organisms.

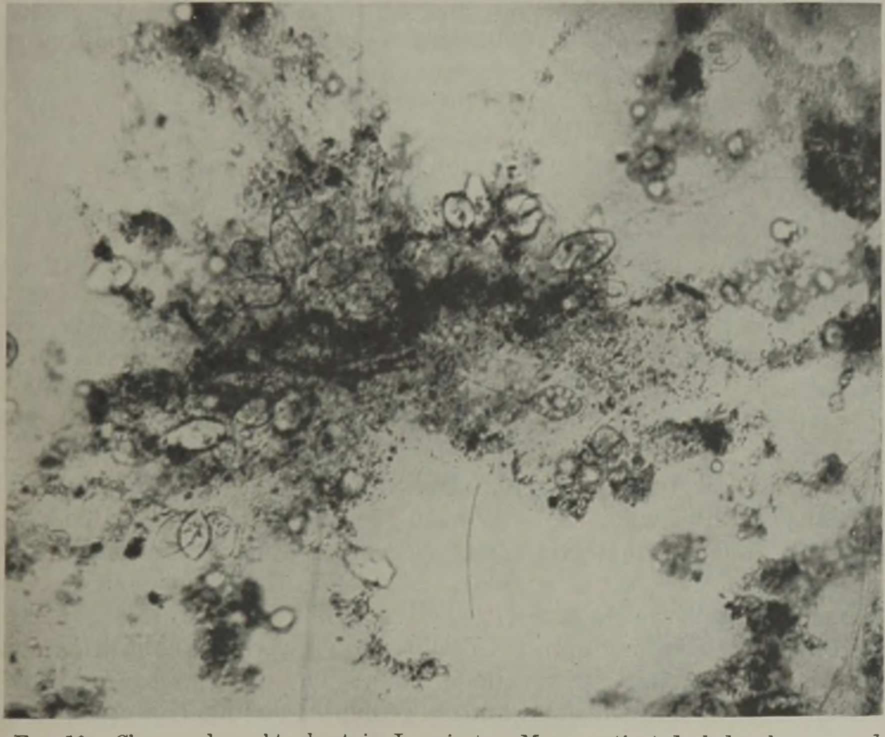

FIG. 10.—Changes brought about in Leominster, Mass., activated sludge by seven days of incremental dosing with Cambridge sewage in Sample *B* of Experiment 1. Note the large number of short-stalked, enmeshed, colonial ciliates.

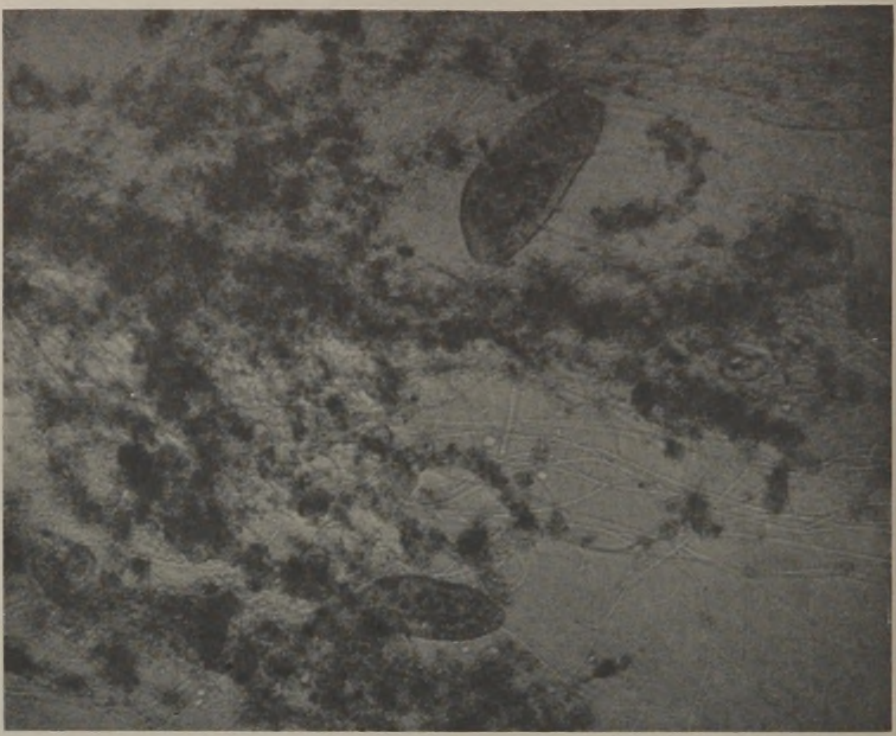

FIG. 11.—Sludge activated in the Laboratory and used at the start of Experiment 2. Note the abundance of filamentous organisms and motile ciliates.

taken at the plant, was about 300, *Sphaerotilus* was not noticeably present and a good effluent was being produced. After seven days of feeding, photomicrographs of typical fields (Figs. 9 and 10) exhibit a very different appearance. Filamentous organisms are seen to have decreased in number together with long-stalked colonial ciliates. *Vorticella* and *Opercularia* are still in evidence but are enmeshed in the gelatinous matrix of the floc and so rendered relatively inactive. On the whole, life appears to have been more motile in Sample B, which was subjected to incremental dosing, than in Sample A, which was dosed in the conventional manner. Motile ciliates, *Euplotes,* as well as short-stalked *Opercularia,* are observed to have been numerous in Sample B. During their seven-day exposure to Cambridge sewage, both samples had lost their gray-brown hue and had become quite black. A similar change was generally noted when Leominster sludge was fed on the domestic sewage supplied to the laboratory. The color change is in accordance with Sawyer's observation (7) that activated sludge developed from strictly domestic sewage becomes dark brown in color or humus-like black.

Experiment 2 was begun with activated sludge that had been generated in the laboratory plant. As shown in Fig. 11, it contained many filamentous organisms and motile ciliates. The changes brought about in seven days by conventional and incremental dosing (Samples A and

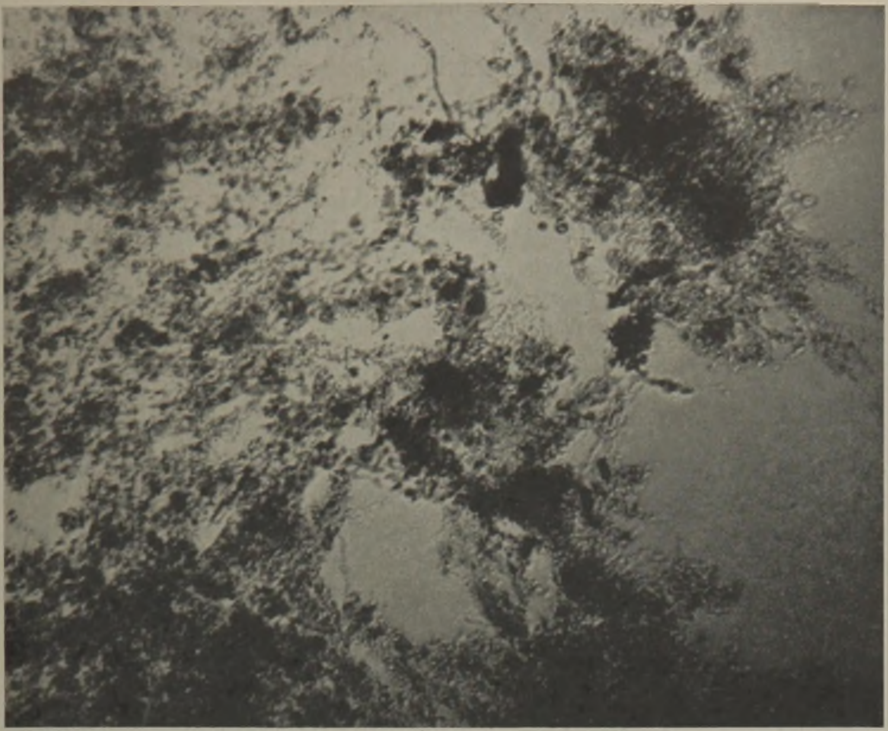

FIG. 12.—Changes brought about in Laboratory activated sludge by seven days of conventional dosing in Sample *A* of Experiment 2. Note the absence of protozoa.

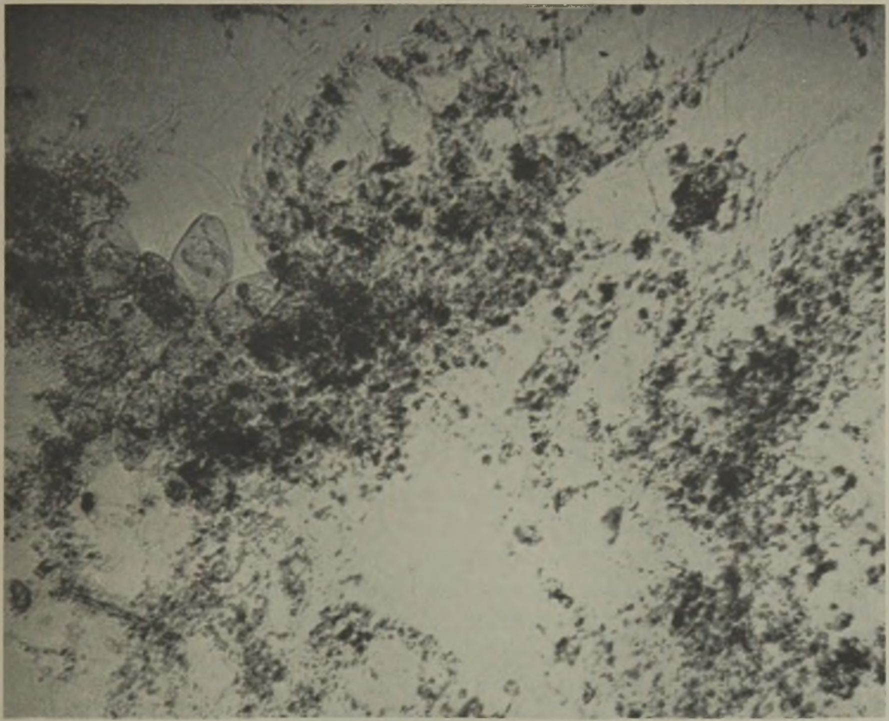

FIG. 13.—Changes brought about in Laboratory activated sludge by seven days of incremental dosing in Sample *B* of Experiment 2. Note the large number of filamentous organisms and of short-stalked and motile ciliates.

B respectively) are illustrated in Figs. 12 and 13. Sample A, with a specific volume of 139, was dense, black, and more or less static in appearance. A few motile and short-stalked ciliates were in evidence. In Sample B, with a specific volume of 325, on the other hand, *Sphaerotilus, Euplotes* and *Opercularia* were abundantly present.

The microscopic changes observed in both experiments were due probably very largely to excessive agitation of the mixtures of sewage and sludge in the equipment employed. It seems reasonable to expect that long-stalked colonial ciliates like *Vorticella* are well adapted to the gentle motion of spiral-flow aeration tanks and poorly adapted to the more violent agitation to which they had to be subjected in the flasks illustrated in Fig. 1. Long-stalked, fragile organisms, therefore, were understandably replaced by short-stalked, more robust organisms within the same family or group. At the same time the size of the flocs themselves appears to have been reduced by agitation, calling for an adjustment of the organisms to the changed opportunities for anchorage. That incremental dosing appears to have done better under the conditions of these two, as well as other similar, experiments is of more than passing interest in connection with tank operation.

Practical Aspects and Implications of Load Distribution

Many questions remain to be answered before engineers can be expected to be willing to proceed to the use of load distribution in the design and operation of plants on a large scale and thereby to the definitive evaluation of the merits of this modification of the activated sludge process. The manner in which load distribution appears to lend itself to practical use is, nevertheless, believed to be of sufficient interest to be deserving of brief discussion.

Saving in Tank Volume.—For an analysis of the saving in tank volume made possible by incremental dosing, let us adopt the following notation (see Figs. 14 and 15).

Q = rate of sewage flow in c.f.s.
p = proportion of returned sludge, making pQ the rate of flow of returned sludge in c.f.s.
t = time of displacement of mixed liquor from end to end of the aeration tank in seconds.
t_D = time during which sewage is added incrementally along the path of flow in seconds; $t_A = t - t_D$.
V = volume of tank for conventional operation in cu. ft.
V' = volume of tank for distributed loading in cu. ft.
V_D = volume of tank along which sewage is added incrementally in cu. ft.; $V_A = V' - V_D$.
N = number of compartments in a baffled tank.
N_D = number of compartments in which sewage is added incrementally.
n = any integer from 1 to N.

L = distance between baffles of compartments to which sewage is not added incrementally, or of compartments in a conventionally operated tank.

L_n = distance between baffles of nth compartment to which sewage is added incrementally.

If the full flow of sewage and returned sludge are brought together as in the conventional operation of aeration units, the total tank volume needed is:

$$V = (p + 1)Qt. \tag{1}$$

If addition of the sewage is distributed over t_D seconds (Fig. 14):

$$V' = (p + \tfrac{1}{2})Qt_D + (p + 1)Q(t - t_D)$$

or

$$V' = [(p + 1)t - \tfrac{1}{2}t_D]Q. \tag{2}$$

It follows that the proportion of tank volume saved by incremental dosing is:

$$\frac{V - V'}{V} = \frac{1}{2(p + 1)}\frac{t_D}{t}. \tag{3}$$

The range of results obtained under normally conceivable conditions is shown in Table III. Probable savings are enclosed in a rectangle within the table and are seen to lie between 23 and 35 per cent of the tank capacity.

TABLE III.—*Percentage Saving in Tank Volume by Incremental and Multiple-Point Dosing:*

$$100\,\frac{V - V'}{V} = \frac{50}{(p + 1)}\frac{t_D}{t} \text{ or } \frac{50}{(p + 1)}\frac{N_D - 1}{N}$$

Per Cent of Time Allowed for Dosing*	Per Cent of Returned Activated Sludge (100 p)							
	5	10	15	20	25	30	40	50
90	42.9	40.9	39.1	37.5	36.0	34.6	32.1	30.0
85	40.5	38.6	37.0	35.4	34.0	32.7	30.4	28.3
80	38.1	36.4	34.8	33.3	32.0	30.8	28.6	26.7
75	35.7	34.1	32.6	31.2	30.0	28.8	26.8	25.0
70	33.3	31.8	30.4	29.2	28.0	26.9	25.0	23.3
65	31.0	29.5	28.3	27.1	26.0	25.0	23.2	21.7
60	28.6	27.3	26.1	25.0	24.0	23.1	21.4	20.0
55	26.2	25.0	23.9	22.9	22.0	21.2	19.6	18.3
50	23.8	22.7	21.7	20.8	20.0	19.2	17.9	16.7

* $100\,\frac{t_D}{t}$ or $100\,\frac{N_D - 1}{N}$.

Need for Baffles.—Observation of aeration tanks, particularly of spiral-flow units, will show that the rate of longitudinal travel of the mixed liquor is small in comparison with the velocities imparted to it by the air. The direction of the imparted motions, furthermore, is random and may project individual portions of the liquor upstream, across the tank, or downstream. The result is the establishment not only of transverse circulation but also of longitudinal mixing of the tank contents. Calvert and Bloodgood (8) have shown that longitudinal mixing is sufficiently strong at Indianapolis to carry sludge from the half-way mark of spiral-flow tanks back to the influent end, 238 ft. away; of course in reducing concentrations. In the absence of transverse baffles, therefore, longitudinal mixing may establish, under conventional conditions

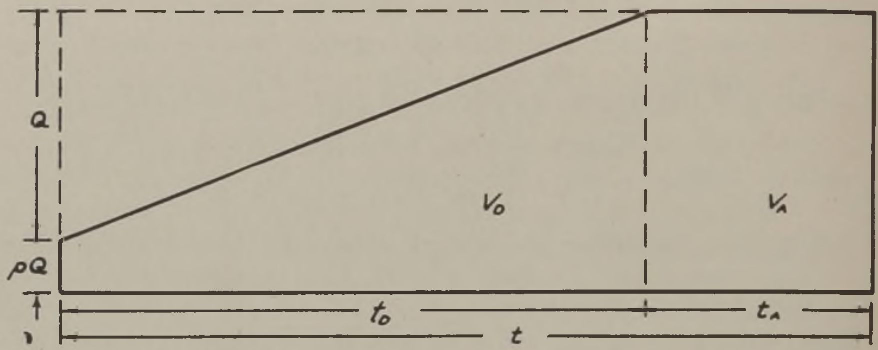

FIG. 14.—Graphical analysis of the saving in tank volume effected by incremental addition of sewage along the line of flow. Required volume is given by the sum of the areas under the trapezoid and rectangle.

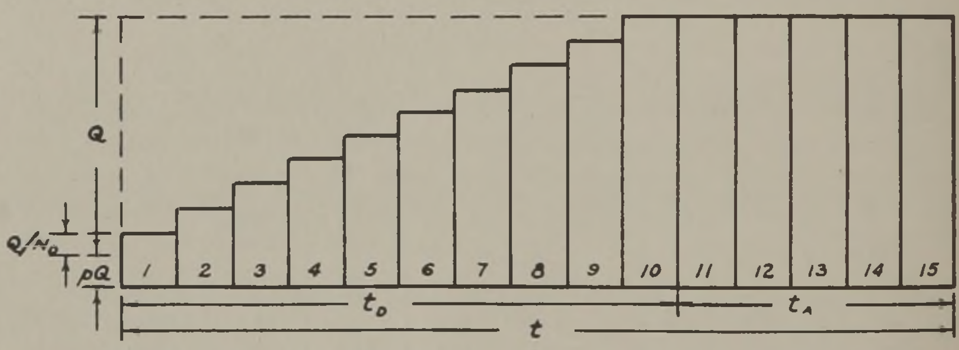

FIG. 15.—Graphical analysis of the saving in tank volume effected by multiple-point addition of sewage along the line of flow. Required volume is given by the sum of the successive rectangular areas.

of operation, the partial but unrecognized equivalent of distributed loading adversely affected, however, by short-circuiting. If control of tank operation is to be ensured, therefore, a sufficient number of baffles must be inserted to keep longitudinal mixing within bounds no matter what the method of operation.

Since there will still be longitudinal mixing between baffles, it is not practical to employ load distribution to the fullest extent, *i.e.* to introduce sewage into the aeration units uniformly along a given stretch of their length. *Multiple-point dosing* must be resorted to by discharging definite proportions of the total flow into successive compartments of the tanks that are formed by suitable transverse baffles. If the proportions of the sewage flow and the periods of detention of the mixed liquor are made the same for all compartments (not a necessary condition), the resultant saving in tank volume may be formulated in much the same way as before (Fig. 15).

The quantity of mixed liquor entering the nth compartment will be $\left(p + \frac{n}{N_D}\right) Q$, the detention period $\frac{t}{N}$, and the volume $\left(p + \frac{n}{N_D}\right) \frac{Qt}{N}$ when n is less than $(N_D + 1)$. Since n can vary from 1 to N_D:

$$V' = \left(pN_D + \frac{N_D + 1}{2}\right) \frac{Qt}{N} + (p + 1) \frac{Qt}{N} (N - N_D)$$

or

$$V' = [(p + 1)N - \tfrac{1}{2}(N_D - 1)] \frac{Qt}{N}. \tag{4}$$

The proportion of tank volume saved by multiple-point dosing, therefore, is:

$$\frac{V - V'}{V} = \frac{1}{2(p + 1)} \frac{N_D - 1}{N}. \tag{5}$$

Table III again indicates the range of results normally obtainable.

If the cross-section of the aeration units is to be held constant throughout their length, a probable structural requirement, the changes in volume of the successive compartments can be secured by choosing the distances, L_n, between successive baffles so that they will vary directly as the quantity of mixed liquor passing through the compartments, or for n less than $(N_D + 1)$:

$$\frac{L_n}{L} = \frac{\left(p + \frac{n}{N_D}\right)}{(p + 1)}. \tag{6}$$

To illustrate the result, let us say that a conventional tank is to be 150 ft. long and contain 15 compartments (L = 10 ft.). Table III shows that 10-point dosing $[100(N_D - 1) \div N = 60]$ will reduce the length of this tank by 25 per cent, *i.e.*, to 112.5 ft., assuming that the volume of returned sludge is to be 20 per cent of the sewage flow in both cases. Equation 6 then assigns the following values to the spacing of the first 10 baffles, the remainder being placed at 10-ft. intervals:

Compartment No.:	1	2	3	4	5	6	7	8	9	10
Spacing, ft.:	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0

Elements of Tank Design.—On the strength of their studies, the authors are of the opinion that aeration units that are to include the principle of load distribution should desirably incorporate the following features:

1. Aeration of the sewage for about 30 minutes prior to its addition to the returned activated sludge in order to saturate it with oxygen (preaeration).

2. Aeration of the returned sludge for a sufficient time to satisfy its immediate oxygen demand (reaeration).
3. Multiple-point introduction of sewage along the line of flow (load distribution) to save tank volume and improve operation.
4. Installation of an adequate number of adjustable baffles (ten or more) in order to restrict longitudinal mixing and reduce short-circuiting.

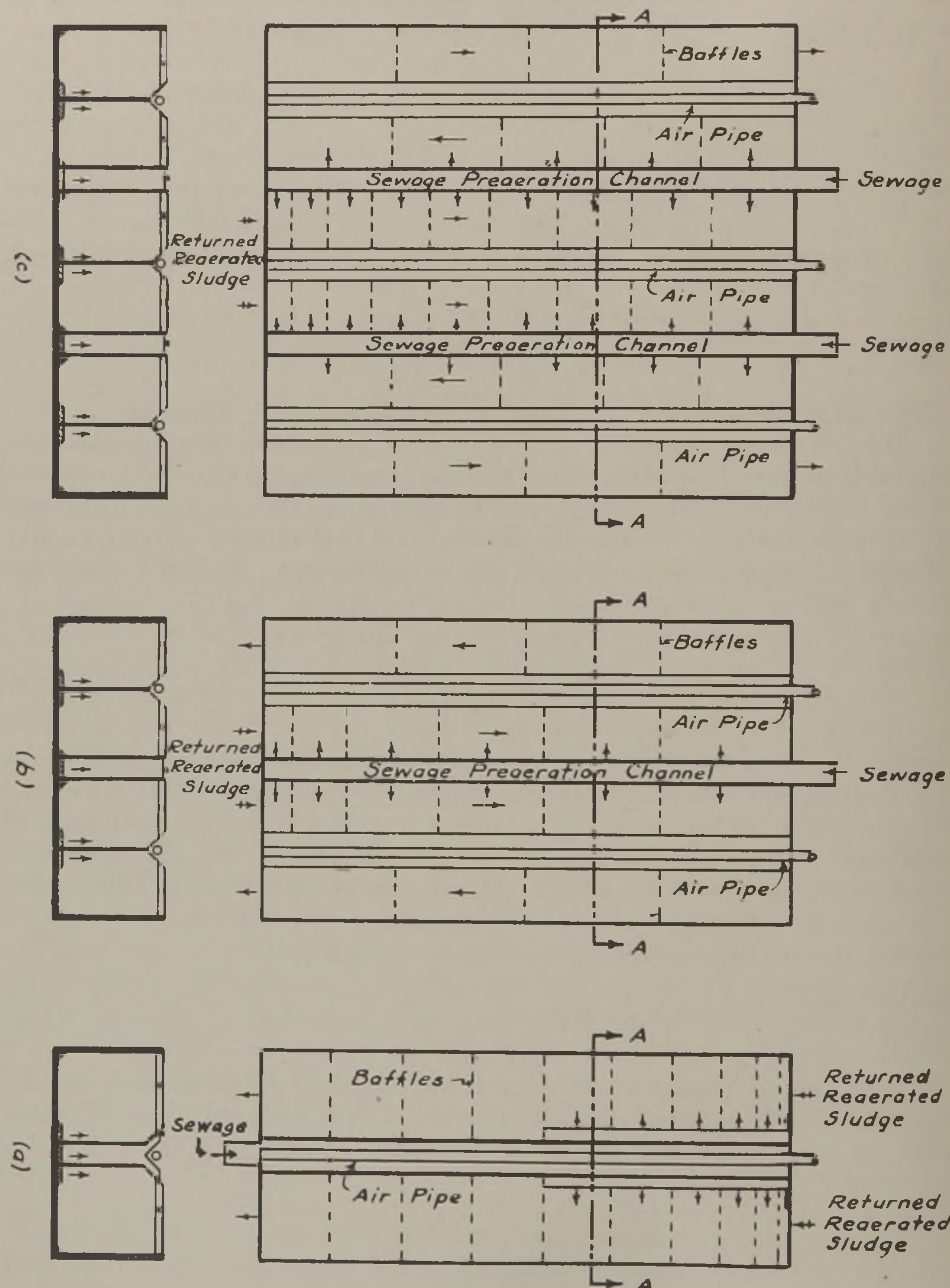

FIG. 16.—Possible arrangements of spiral-flow aeration units that incorporate preaeration and multiple-point dosing of sewage.

5. Aeration of mixed liquor for about 1½ hours after receipt of the last incremental dose of sewage for the purpose of absorbing the impurities introduced with the last dose of sewage (see later).
6. Provision of an adequate number of gated or otherwise controllable sewage inlets in order to render operation as flexible as possible.

A number of possible structural arrangements of aeration tanks are sketched in Fig. 16. The two parallel units of Fig. 16(*a*) are divided into ten compartments. Six of these are dosed from a common inlet channel which serves also as a preaeration chamber in which the sewage flows counter to the direction of the mixed liquor. The two return-channel units of Fig. 16(*b*) are separated by a preaeration channel that discharges into six compartments on each side. The four compartments of each return channel do not receive sewage. Double reversal of flow is illustrated in Fig. 16(*c*). Multiple-point dosing is accomplished by providing two preaeration channels that serve the first 14 of 18 compartments. Arrangements other than the three here described will suggest themselves to suit local requirements as well as differences in engineering taste.

Modification of Existing Tanks.—Since load distribution saves tank volume, this modification of the activated sludge process may find useful application in existing plants that have become overloaded in the course of time or that have become overtaxed by sudden shifts in population or industrial activity. In Figs. 17 and 18, possible modifications of existing works are suggested. In both units, baffles are inserted to reduce short-circuiting by creating ten compartments. In Fig. 17, sewage is sprayed into the first six compartments and is so preaerated. This sewage must be pumped. In Fig. 18, pumping is avoided by giving over part of the original unit to a preaeration chamber from which a pipe carries sewage to the first six compartments. This pipe is placed suitably above the air diffusers. It stands to reason, however, that each plant and each sewage are laws to themselves and that multiple-point dosing by itself or combined with preaeration and reaeration, if introduced, will have to pay due regard to local conditions.

Elements of Tank Operation.—Incremental operation of aeration units may be guided to some extent by the following considerations: (1) enough sewage should be added to the first compartment of the aeration units to arrest autolysis, or self-digestion of the sludge, *i.e.* the rate of respiration of the mixed liquor should be observed to rise, and (2) incremental dosing should be stopped sufficiently short of the end of the tank to permit adsorption and flocculation of impurities from the sewage to be completed before the mixed liquor is passed to the final settling tanks, *i.e.* the rate of respiration of the mixed liquor should be made to drop to the basic oxygen demand of the returned sludge by the end of the aeration period. According to Ruchhoft and his coworkers (9) adsorption and flocculation reach equilibrium in 30 to 40 minutes. In view of unavoidable dispersion of sewage by longitudinal mixing, a detention period of 1½ hours would, however, not appear to be too long.

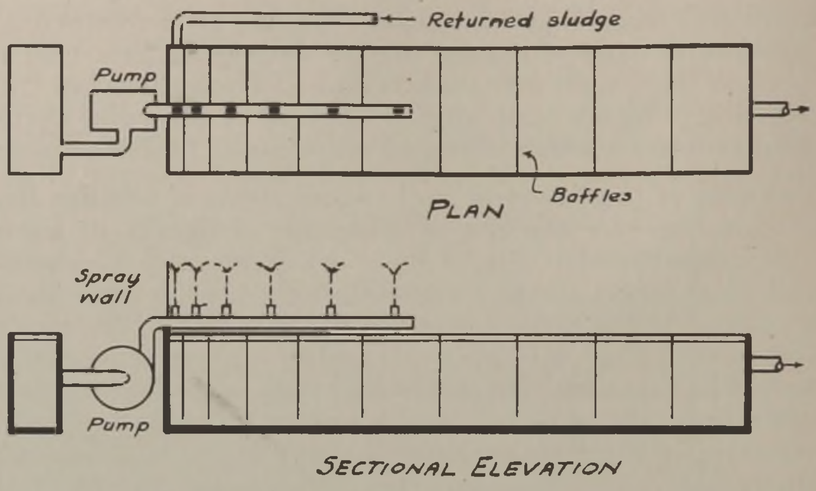

FIG. 17.—Modification of existing aeration tank by spray distribution of incoming sewage for preaeration and multiple-point dosing.

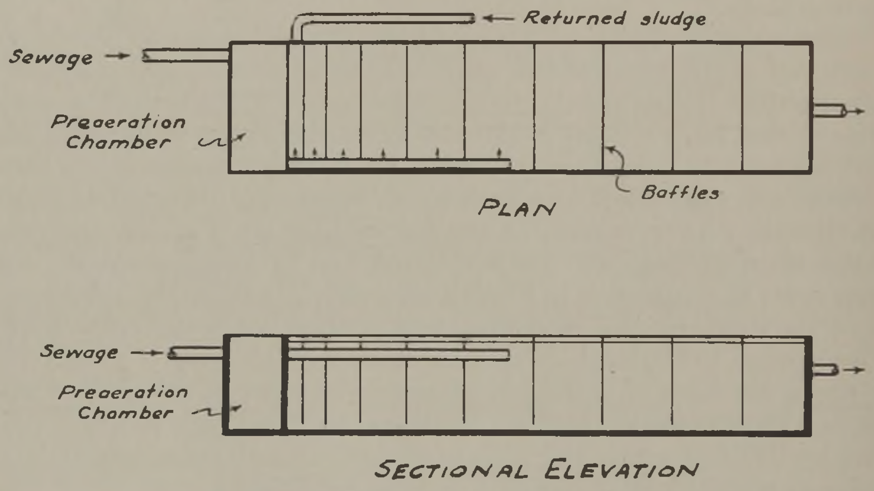

FIG. 18.—Modification of existing aeration tank by including preaeration and multiple-point dosing of sewage.

Unpublished studies by the junior author have shown that very little sewage would then be subjected to less than 30 minutes of treatment provided that three or four baffles intervened between the point of last dosing and the end of the aeration tank.

To compare the idealized operation of aeration units, oxygen-demand curves for conventional and incremental dosing are outlined in Fig. 19. Here Line A represents the base rate of the returned sludge, Line B the rate associated with conventional dosing, Line C the minimum rate that would obtain if respiration were made uniform and the sludge were fed adequately and continuously—regardless of effluent standards—during the full detention period, t, and Line D the rate attainable with incremental dosing in time t_D, due regard being paid to the quality of the effluent. It should be noted (1) that the oxygen requirements of the mixed liquor (B, C, D) are superimposed on the base rate of the sludge (A), indicating that an ideal period of aeration has been chosen and that the returned sludge is neither overloaded nor starved; (2) that Line B tapers off to the initial base rate of the sludge; (3) that the line of minimum demand (C) terminates well above this rate and so is of no practical use; and (4) that Line D reaches this rate by rising above Line C initially and dropping sharply below it after completion of the dosing period. When the rate of respiration of the mixed liquor does not taper

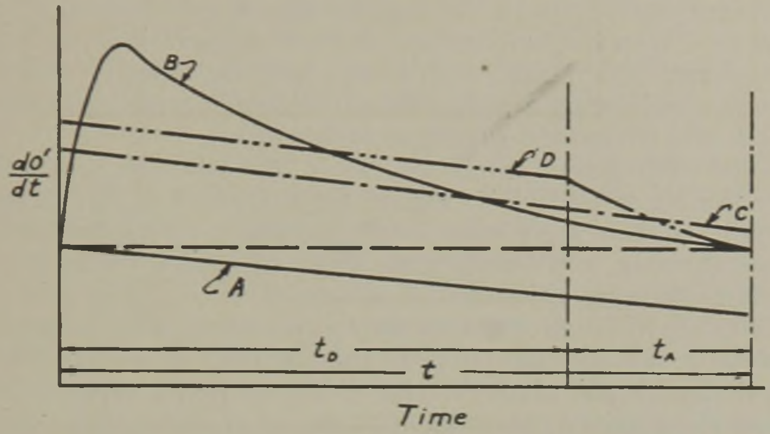

FIG. 19—Idealized rates of oxygen demand, dO'/dt, of: *A*. Returned activated sludge alone (base rate). *B*. Mixed liquor in conventional operation. *C*. Mixed liquor in incremental operation during the full detention period, *t*. *D*. Mixed liquor in incremental operation during the dosing period, t_D.

off as indicated for Lines B and D, the sludge is probably being overloaded. Prolonging the period of aeration or increasing the concentration of suspended solids in the mixed liquor by returning more sludge may correct this situation. Because load distribution works with a high initial concentration of returned sludge, it may be expected to permit carrying lower average concentrations of suspended solids than conventional dosing.

If operation is made sufficiently flexible, it is believed that load distribution will lend itself to the control of blanket rising by permitting the return of less sludge, reducing the period in service of the sludge, and maintaining a lighter, more active floc. Sludge bulking, which appears to be associated in particular with overloading and underaeration of the sludge, on the other hand, would seem to be amenable to control particularly by preaeration of sewage, reaeration of sludge, and increased aeration of mixed liquor; but incremental dosing should be of some service, too, by reducing the possibility of shock which Ruchhoft and Kachmar (10) believe to be largely responsible for sludge bulking.

Summary and Conclusions

This paper presents a laboratory investigation of the effects of load distribution on the activated sludge process and incorporates comprehensive suggestions for a modification of new and existing activated sludge plants by equipping them for multiple-point dosing in the fullest sense of the meaning of this term. It is realized that many details of the incremental method remain to be worked out and evaluated and that plant-scale tests will have to be conducted before the true value of the method is ascertained. With these limitations in mind, the following broad conclusions are offered with the suggestion that they be interpreted conservatively.

1. Load distribution appears to provide a workable modification of the activated sludge process by maintaining oxygen demand at a more uniform level than the conventional method of operation, producing an indigenous activated sludge with good purifying capacity and settling properties, discharging a good effluent without increasing the air consumption, and effecting a saving in tank volume.

2. Load distribution seems to render operation of aeration units flexible, making it possible to adjust the character of the sludge produced to the needs of the sewage treated, aiding in the control of bulking and blanket rising, and reducing the shock of sudden discharges of industrial or otherwise objectionable wastes.

3. Load distribution requires no special equipment, is readily incorporated in conventional tanks by the provision of sewage inlets and transverse baffles, and gives promise of increasing the capacity of overloaded aeration units by more effective use of available tank volumes.

4. Preaeration of sewage and reaeration of returned sludge, too, appear to be of importance in equalizing the oxygen demand of activated sludge units.

5. Installation in aeration units of an adequate number of baffles is essential to the control of longitudinal mixing and short-circuiting that will otherwise prevail.

The subject matter of this paper formed the basis of portions of a thesis prepared by the junior author under the direction of the senior author in partial fulfillment of the requirements for the degree of Doctor of Science in the Graduate School of Engineering of Harvard University.

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Discussion

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It is presumptuous to comment on as scientific a paper as this presented by Drs. McKee and Fair. The simplicity and directness of the study are indicative of the thought and effort put into this work.

Briefly, their conclusions indicate the probability that the activated sludge process can be carried out more satisfactorily by multiple point or incremental dosing than by the present conventional process, because of the maintenance of a relatively uniform rate of oxygen utilization during the period of dosing. The use of their proposed method is expected to result in a reduction of aeration tank volume for a given aeration period. Both preaeration of sewage and reaeration of activated sludge are desirable supplements to their process.

As the authors have stated, the work is in an early period of study, and many questions that are readily apparent have not been fully answered. The following are a few of the questions that have occurred to us:

1. Is it advantageous to level the rate of oxygen utilization by zones in the aeration tanks?

It appears logical, without supporting experimental data, that this might be a desirable thing to do. If, however, the use of the proposed method results in unanticipated difficulties, it is possible that the application may not be worth the resulting benefits. In the conventional method of operating the activated sludge process we find that several tenths of a part per million of dissolved oxygen are present in the mixed liquor at the influent end of the aeration tanks. Part of this oxygen concentration is due to back circulation and longitudinal mixing. Are these low oxygen concentrations sufficient to provide an adequate oxygen supply to the desirable organisms and do they tend to stimulate the growth of such undesirable organisms as filamentous bacteria? If these low dissolved oxygen concentrations are detrimental to the activated sludge, the possibility of obtaining a higher level of dissolved oxygen in the aeration tanks by multiple point dosing should be investigated.

2. Is the conclusion that the same order of degree of treatment is obtained by the conventional method and the proposed method justified by the experimental data?

There is no question that under the particular conditions of the experimental data indicated in Table II that this conclusion is justified; however, is it not possible that because of a long aeration period and the large amount of air used that the degree of purification in the two processes tend to approach each other regardless of a possible difference in their purification rates?

The "blanket rising" effect noted in the sludge in the conventional method of treatment in the author's experiment is associated in our experience with over-aeration. This, together with the gradual reduction of volatile matter in the sludge, indicates excessive application of air in these experiments.

3. Is the higher specific volume or sludge index of the incrementally dosed experiment a characteristic of the proposed process?

Should this be the situation it is a serious handicap to the suggested process, for while good B.O.D. reductions can be obtained with sludge of high specific volume, the control of the sludge in the final settling tanks and the ultimate disposal of the sludge is made very difficult.

We have the problem of operating a plant with an activated sludge of high specific volume most of the time. We are able to operate continuously with removals of B.O.D. and suspended solids in the order of 90 per cent and we find that during periods of moderately high specific volume sludges, we produce better effluents than during similar periods of low sludge specific volumes. However, constant vigilance is necessary during periods when the sludge has high specific volume. We have observed that sludges of low specific volumes, containing practically no filamentous bacteria, have relatively stable specific volumes, whereas sludges containing large quantities of filamentous bacteria are most unstable in this regard. We determine sludge settling rates and aeration liquor solids every two hours and adjust return and waste activated sludge pumping rates after each test. The need for this control is brought about by our experience that the specific volume of the sludge can double in a four-hour period.

Sludge of high specific volume makes final sludge disposal by digestion a difficult problem. Where activated sludge is concentrated in primary settling tanks the efficiency of these tanks is greatly reduced, due to excessively high specific volume sludge, and sludge digester and storage capacities are apt to be rendered inadequate because of low solids concentrations in the sludge pumped to them. We have found it necessary to provide additional storage tank capacity in our plant because of this condition.

In the proposed process several of the suggested modifications are particularly attractive to us.

The use of preaeration of sewage before addition to the activated sludge is in our opinion sound. It not only serves the purpose of reducing the rate of oxygen utilization but it also reduces the oxygen demand of the waste, particularly in the substrate, and tends to level out variations in B.O.D. concentrations. We have conducted plant-scale preaeration studies at Peoria and are convinced that adequate preaeration results in improved operation of the activated sludge process.

The proposed process offers a flexibility of operation not available in the present process, and it affords a control for accomplishing a relatively uniform rate of oxygen utilization during the dosing period.

If the process proves successful the attendant reduction in aeration tank capacity from conventional capacities will of course be desirable both in new plant construction and in existing overloaded plants.

Stream Pollution

BIOLOGICAL STUDIES, OHIO RIVER POLLUTION SURVEY

I. BIOLOGICAL ZONES IN A POLLUTED STREAM *

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Ever since primitive man located his villages on the banks of streams, they have been used as receptacles for waste materials. It has been known for years that the introduction of putrescible organic matter into a flowing stream affects the biological content of the water for a considerable distance downstream (1, 2, 3). The degree of alteration on the whole tends to be a logarithmic function of the time, from the point of pollution, and is largely dependent upon the kind of organic matter and the physical nature of the stream.

The organic matter introduced into the streams of the Ohio River watershed is largely domestic sewage, waste from canneries, creameries, breweries, distilleries, and paper and pulp mills. Domestic sewage is readily attacked by bacteria and is fairly rapidly decomposed. The waste from creameries, canneries, breweries and distilleries is more slowly decomposed and the cellulose waste from paper mills is very slowly attacked by bacteria. In rapidly flowing streams with smooth bottoms and straight sides, the pollutant may be carried many miles downstream before it is decomposed by bacterial action. On the other hand, a low, sluggish, meandering stream will allow biological and chemical changes to take place in a comparatively short distance below the entrance of the pollutant.

A series of chemical and biological changes take place in a stream below the source of pollution. These changes fall into five well defined zones if the organic matter is of the type that is decomposed by bacterial action, such as domestic sewage, and if the sources of pollution along the stream are sufficiently separated so that the zones do not overlap. These zones or regions in streams have been classified and characterized by a number of workers in stream biology and sanitation (4). In most of these systems of classification of polluted streams, the emphasis has been placed upon the type of chemical changes taking place in a given stretch of water, and such terms as "septic," "polluted," "contaminated" and "cleaner" waters have been suggested as descriptive terms to identify certain sectors of streams.

* From Division of Public Health Methods, National Institute of Health, U. S. Public Health Service.
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In a recent biological survey of the Ohio River Basin (5) it was found that the zones could be defined in terms of the biological population of the water and the dissolved oxygen levels, which are closely related. Only the algal and protozoan plankton, and fish life were studied. Unfortunately, time did not permit a study of the larger zooplankton, which serve as a connecting link in the food cycle between the protozoa, phytoplankton and fish. In this study it was found more satisfactory to consider the volume of plankton expressed in parts per million than to consider numbers of individuals or species that have been considered by other workers (6) as an index to the sanitary conditions of the stream. The total volume, however, has been divided into three classes, depending upon their nutritive requirements. Class I organisms are those that are able to exist and multiply in a medium low in organic material. They are also able to tolerate a more concentrated medium. In this class are included such genera as *Chrysococcus, Cryptomonas, Dinobryon,* and *Chromulina* and the various genera of diatoms. Class II is made up of those forms which favor a rich medium, or feed upon bacteria and solid particles. In this group are included most species of such genera as *Euglena, Lepocinclis, Phacus, Synura, Anabaena,* and the bacteria-eating ciliates such as *Paramecium, Colpidium* and *Vorticella.* The largest class in numbers and species are those which are able to develop under nutritive conditions that lie between the two extremes. These are lumped together as Intermediates. This class is largely composed of members of the class, Chlorophyceae.

Owing to the probable close relationship between the available food and the plankton population (5), other conditions being favorable, this proposed system of zoning may be a useful field test of the amount of available food for the micro-organisms and, therefore, of the intensity of the upstream organic pollution. This criterion correlates quite satisfactorily with the chemical (biochemical oxygen demand) and bacterial (coli-aerogenes group) tests.

The five distinct biological zones in a polluted stream are characterized as follows (see Fig. 1):

Zone I: Zone of Active Bacterial Decomposition.—This region immediately below the source of pollution is characterized by a low dissolved oxygen concentration (not over 3 p.p.m. and often zero), a high biochemical oxygen demand, and a high bacterial count. The length of this zone depends on the temperature, rate of flow and physical nature of the stream. In the Ohio Basin it varies from a few hundred feet to several miles. Biologically, this region is dominated by bacteria-eating ciliates such as *Paramecium, Colpidium* (Class II), and large numbers of stalked ciliates (*Vorticella* and *Carchesium*) are frequently found attached to the bottom or floating objects, and a few flagellates such as *Chlamydomonas, Chrysococcus* and *Cryptomonas* (Class I) are found occasionally. The total volume of plankton is usually low, less than 2 p.p.m., but may go up to several parts per million. The bottom mud consists largely of sewage sludge and is the favorite habitat of *Tubifex*

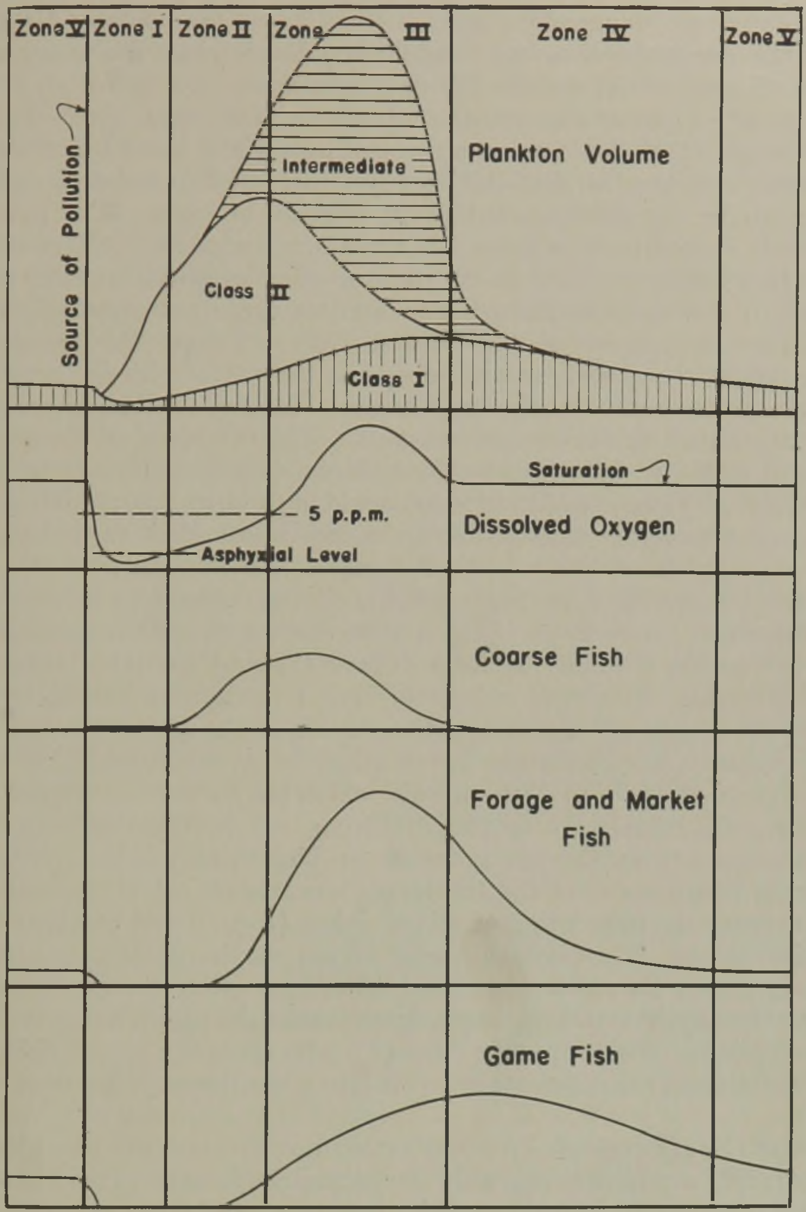

FIG. 1.—Chart showing the five biological zones below the source of domestic pollution.

and *Limnodrilus* worms. This bottom sludge is often brought to the surface by the accumulation of gas derived from bacterial action. Long streamers of sewage fungus are attached to floating and submerged objects. Only a few fish can penetrate this region and they are of the coarse variety such as carp and buffalo. These are usually found at the mouth of the sewer feeding on the fresh sewage. These fish are able to survive the low oxygen concentration because they can come to the surface to gulp air.

A heavy rain, especially during the low water period, may distribute the partly decomposed sewage and sludge downstream for many miles, killing off most of the aquatic life in the stream.

Zone II: Zone of Intermediate Bacterial Decomposition.—Farther downstream, after the teeming masses of bacteria in Zone I have decomposed the sewage, the dissolved oxygen increases to between 3 and 5 p.p.m. during the daytime, but drops slightly at night. The plankton volume is higher than in Zone I but the organisms are still largely of Class II, with an increase in the number of chlorophyll-bearing phytoplankton. Oscillatoria and other blue-green algae are commonly found along the margins and on the bottom of the stream. At times, large masses of blue-green algae are carried to the surface by the accumulation of gas (oxygen from photosynthesis). Masses of filamentous green algae appear along the stream margins. The combined photosynthetic action of all the green plants tends to increase the dissolved oxygen during the day. Fish, in addition to carp and buffalo, are more abundant in species and numbers than in the previous zone. Shiners and various minnows, catfish, suckers and sunfish make their appearance.

Zone III: Fertile Zone.—Zone III is characterized by a large variety and volume of green algae of the intermediate group, accompanied by a decrease in the ciliated protozoa (Class II) and a slight increase in Class I forms. The total volume is over 1 p.p.m. and usually several parts. The immense increase in the growth of the phytoplankton is, in all probability, due to the amount of plant foods made available by the bacterial decomposition of the sewage which has occurred in Zones I and II. Zone III clearly shows the fertilizing and beneficial effects of the decomposed sewage by an increase in biological productivity. The plankton furnishes food for the larger organisms, which furnish food and increase the population of mixed fishes (forage and market) found in this region. The photosynthetic action of the chlorophyll-bearing algae increases the amount of dissolved oxygen often to supersaturation during the daytime, followed by a drop during the night, but usually not below 5 p.p.m. This supports Ellis (7), who gives the figure of 5 p.p.m. as the minimum value necessary to sustain a healthy population of mixed fishes.

Zone IV: Game Fish Zone.—Farther downstream the plankton volume sharply diminishes and only the persistent forms (Class I) remain. The total plankton volume is usually between 1 and 3 p.p.m. The sharp reduction in plankton volume may be due to the utilization of the available food materials by the heavy growth of plankton in Zone III. The dissolved oxygen level remains near the saturation point. Various species of bass, perch, wall-eyed pike and other game and forage fish predominate.

Zone V: Biological Poor Zone.—As the stream reaches purification the plankton volume drops to between 0.5 and 1 p.p.m. and consists almost entirely of Class I plankton. Fish are scarce in number as compared with the previous zone but the types are also mainly forage and game fish. The reduction in fish population is, in all probability, directly or indirectly connected with the low plankton population which, in turn, is due to the low concentration of the available food materials. Many of the fish feed to a considerable extent on terrestrial insects that fall into the water and, therefore, are not a product of the stream. Streams that are classified as "good game fish streams" by the sportsmen are, by the above standards, poor streams biologically.

The zones outlined above are shown as possible phases in a continuous situation, although it is understood that in a given stream certain zones may never appear. In the Cumberland River, for example, we have an almost diagrammatic illustration of the condition depicted, with Nashville serving as the site of pollution. The Miami River, on the other hand, from Dayton, Ohio, downstream, falls entirely in Zones I, II and III. The Wabash River watershed in Indiana, lies in a generally fertile glaciated territory, and its unpolluted regions correspond to Zone IV conditions. Mountain streams, and, in general, the infertile southern streams in their unpolluted reaches, correspond to Zone V. Light pollution may improve them biologically at local points.

The zone into which a given point of a stream may fall will vary with seasons. During spring high water, for example, Zone I and II conditions are scarce. As the year advances and low-flow conditions set in, the polluted areas are more distinct. It should be stressed that it is the summer low-water period that is critical to the fish population of a stream, and not the favorable high-water conditions. A period which exterminates a fish population may be only one day of the year, and is not compensated by the tolerable conditions of the other 364 days.

Summary

A polluted stream may be divided into five zones, depending upon the biological population (plankton and fish).

Zone I. Region of high bacterial action, low dissolved oxygen (not over 3 p.p.m.), plankton volume variable but principally composed of ciliated protozoa (Class II). Carp and buffalo are the only fish found in this region.

Zone II. Dissolved oxygen between 3 and 5 p.p.m. Plankton volume higher than in Zone I, with an increased number of chlorophyll-bearing flagellates, although still composed largely of Class II organisms. Blue-green algae abundant.

Zone III. Dissolved oxygen above 5 p.p.m., and often super-saturation in daytime. Subject to diurnal variation. Plankton over 1 p.p.m., usually several parts per million, largely Chlorophyceae of the intermediate group. Fish are varied and abundant; suckers, sheepshead, catfish and other market fish present.

Zone IV. Dissolved oxygen above 5 p.p.m. and approximating saturation. Plankton between 0.3 and 1 p.p.m., Class II forms scarce. Game and forage fish predominate.

Zone V. Dissolved oxygen near saturation. Plankton less than 1 p.p.m., and consisting almost entirely of *Chrysococcus*, *Cryptomonas* and diatoms (Class I). Fish are scarce, compared with previous zone, but mainly game fishes.

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II. PLANKTON ALGAE AS INDICATORS OF THE SANITARY CONDITION OF A STREAM *

BY FLOYD J. BRINLEY

U. S. Public Health Service, Cincinnati, Ohio

The algae population of a stream depends largely, in final analysis, upon the amount and kind of food in the water. The food is composed of inorganic and organic salts, dissolved from the soils and rocks over which the stream flows, and organic matter that is carried into the stream from the surrounding area by means of rains or from cities by way of sewers.

Kolkwitz and Marssons, Forbes and Richardson and others have studied the food relationship of various planktonts and have attempted an ecological classification of the organisms in regard to their food requirements (see Whipple (1)).

Due to their sensitivity to changes in the environment, their rapid growth under favorable conditions, and their large size compared to bacteria, the plankton algae have been used as indicators of the sanitary conditions of a stream. Purdy (2), Forbes and Richardson (3), Richardson (4), and more recently, Lackey (5) have shown that certain planktonts favor a rich medium and are found in significant numbers below regions of heavy organic pollution. Others are not adapted to a medium of high organic matter and grow better in "cleaner" waters. These investigators have used as indices of the degree of pollution such

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factors as, the general appearance of the stream, the distances below sewer outlets, and the bottom sludge deposits, which may or may not give an accurate picture of the sanitary condition of the stream at the exact time and place the plankton samples were taken.

Lackey (5) has pointed out that there are a number of species of plankton algae that may be satisfactorily used as indicators of the sanitary condition of a stream. Two genera, *Chrysococcus* and *Cryptomonas,* are stated by Lackey to be particularly well adapted to clean water and several species of *Euglena, Trachelomonas crebea, T. urceolata, Cryptoglena pigra, Lepocinclis texta* and *Phacus pyrum,* prefer polluted waters.

While conducting a biological survey of the Ohio River basin (6), the author was in a position to make a comparative study of the relationship of certain species of plankton algae to the biochemical oxygen demand and to the numbers of coli-aerogenes bacteria. These factors have long been used by the Public Health Service and other agencies conducting pollutional studies as an index of the degree of organic pollution. The biochemical oxygen demand (B.O.D.) refers to the amount of oxygen disappearing from a sealed sample of water at 20° C. in the course of five days. These values express the total amount of pollution by putrescible organic matter. The number of coli-aerogenes bacteria gives a more accurate picture of the degree of pollution by human sewage.

This report is based largely on the data obtained from a study of a stretch of about eighty miles of the Miami River, from the mouth to Dayton, Ohio. This region is heavily populated and the sewage from several towns, in addition to the organic and industrial waste from creameries, canneries and paper and pulp mills, is emptied into the stream. Some of these towns have sewage treatment plants, but the majority pour their raw waste directly into the river. Fifty-two samples were taken at different locations along this portion of the stream at various times from June 28 to October 31, 1939. During this period the stream was in a fairly stable, low-flow condition, and only two rains occurred—on July 1 and September 4—which were sufficiently heavy to muddy the water. Light rains fell throughout the summer but they had but little effect on the stream. The temperature varied from 17° to 25° C., except when a cold snap occurred on October 13, when the temperature dropped to 12° C. The chemical and bacteriological analyses were made by members of the respective departments of the Stream Pollution Investigations at Cincinnati, Ohio.

Clean Water Forms

The relation of the distribution of *Chrysococcus rufescens* and *Cryptomonas erosa,* which are considered by Lackey (5) to be indicative of clean water, to the coli-aerogenes bacteria population and the 5-day B.O.D. is expressed in Fig. 1. The number of plankton and the bacteria population and the biochemical oxygen demand values were all low on

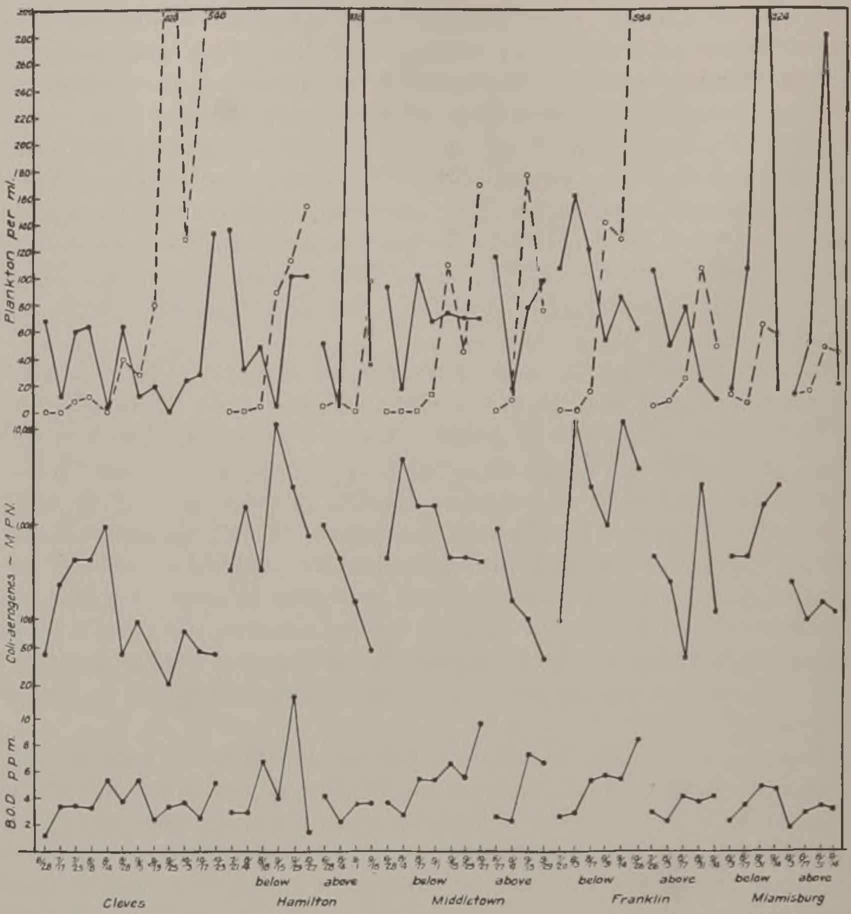

FIG. 1.—Chart showing the B.O.D. coli-aerogenes and plankton values taken at various stations along the Miami River on the dates indicated. Solid line gives the number of *Cryptomonas erosa* and the dotted line represents the population of *Chrysococcus rufescens.*

June 28 at the mouth of the river (Cleves) due to a previous washing out of the stream by a series of heavy rains. Following June 28 the number of bacteria gradually rose to a maximum on August 14. This peak was accompanied by a decrease in the plankton and a drop in the bacteria population. A bloom of *Chrysococcus* and a slight increase in *Cryptomonas* occurred in October. The *Cryptomonas* curve show an inverse relationship to the B.O.D. except on October 23 when they both showed a slight rise.

Below Hamilton the bacteria and B.O.D. curves varied inversely to the numbers of *Cryptomonas.* The *Chrysococcus* population was high toward the end of the season but the bacteria and B.O.D. values were low. Above Hamilton, a bloom of *Cryptomonas* occurred on September 1. The number of bacteria decreased gradually during the season and B.O.D. values were generally low, between 2 and 4 p.p.m. *Chrysococcus* numbers were low during the first part of the summer, increasing with the high bacteria counts. The plankton rose on September 15, and the bacteria dropped.

Below Middletown, the bacteria and B.O.D. curves varied in inverse relation, which was possibly due to the operation of canneries in Middletown during September and October. The plankton and bacteria curves also varied inversely. The plankton population was low on August 4 and the number of bacteria was high. The bacteria count dropped in September and October and the plankton, especially *Chrysococcus*, showed a prominent rise. Above Middletown, the bacteria showed a rapid drop from June 27 to September 29 and the plankton population showed a general increase towards the end of the season. A high *Cryptomonas* population occurred on June 27. The high B.O.D. values during the latter part of September were again probably due to the operation of canneries in Franklin.

The bloom of *Chrysococcus* which occurred on October 26, below Franklin accompanied a drop in bacteria. The high *Cryptomonas* population on August 3 did not agree with the high bacteria numbers found on that date, but did agree with the low B.O.D. Above Franklin, the low plankton and B.O.D. values and generally low bacteria count may be attributed to wastes from a paper and pulp mill.

Below Miamisburg, there occurred a bloom of *Cryptomonas* on August 31 which agreed very well with the low B.O.D. values of that period. The *Chrysococcus* population, however, showed only a slight rise on that date. Another bloom of *Cryptomonas* occurred above Miamisburg on October 31, accompanied by low chemical and bacteriological values. The *Chrysococcus* population, above town, increased slightly on August 31.

Figure 1 shows a general agreement between the B.O.D. and the coli-aerogenes bacteria, except where the B.O.D. values are increased by the addition of industrial organic matter. There is a general inverse relationship between the plankton and bacterial curves. The blooms of *Cryptomonas* occurred in August, while those of the *Chrysococcus* was prevalent during the latter half of September and October. There seems, therefore, to be a slight seasonal effect. It is interesting to note that when the *Chrysococcus* population was high the number of *Cryptomonas* was low. Likewise, when blooms of *Cryptomonas* occurred, *Chrysococcus* numbers were low. These blooms of plankton undoubtedly occur when all environmental factors are at an optimum for that particular species. As these two genera are widely distributed, at least over the Ohio River basin, and are easily identified in fresh and preserved material, and can withstand low temperatures, they may prove satisfactory indices for water that has passed through the stage of natural purification. However, caution must be practiced in using any one factor as an index of the degree of pollution.

Practically all samples of water, even though heavily polluted, will show the presence of a few of these forms, so it must not be taken for granted that the presence of these forms indicates purified water, or that their absence indicates a polluted condition.

Pollutional Forms

The genus, *Euglena,* consisting largely of the following species, *pisciformis, acus, oxyurus, polymorpha, gracilis* and *viridis,* and *Trachelomonas crebea* and *urceolata* are organisms that normally required a medium rich in organic matter. There may be some difference between the various species of *Euglena* in regard to their nutritive requirements, but as it is extremely difficult to identify some of the species in preserved material, the genus, *Euglena,* is here studied as a unit. The result of the study of the distribution of *Euglena* and *Trachelomonas* in relation to the coli-aerogenes bacteria and biochemical oxygen demand is represented in Figs. 2 and 3. A study of Fig. 2 shows there

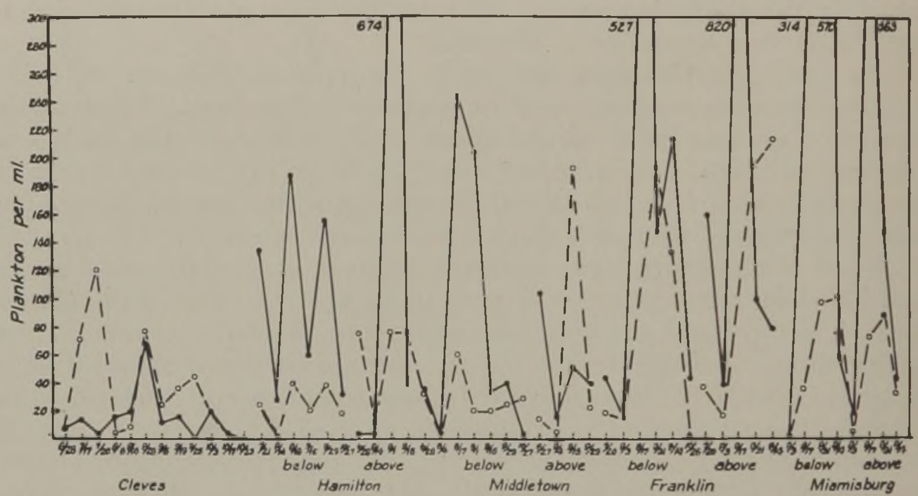

Fig. 2.—Solid line shows the number of *Euglena* spp. and the dotted line, the population of *Phacus lenticularis.* Samples taken at the same stations and on the dates as indicated in Fig. 1.

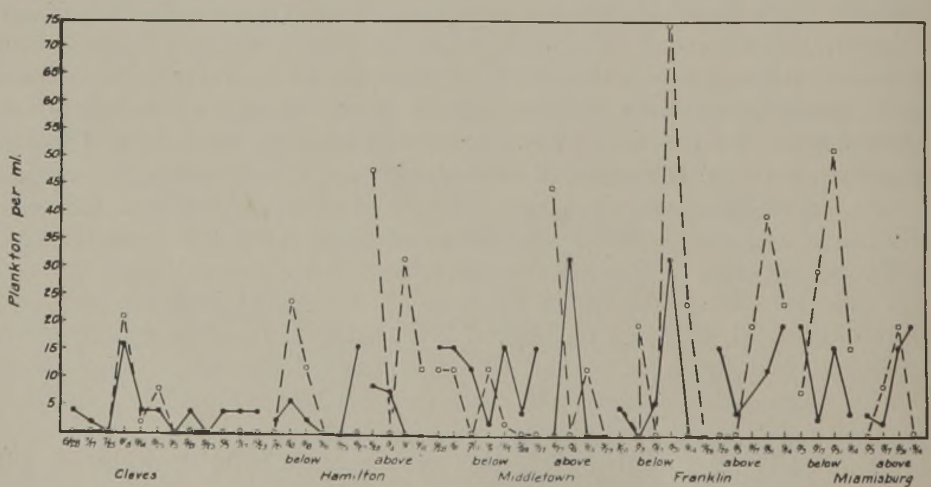

Fig. 3.—Solid line shows the number of *Trachelomona urceolata* and the dotted line represents the population of *T. crebea.* Samples taken at the same stations and on the same dates as Fig. 1.

is no agreement between the chemical and bacteriological data and the distribution of *Euglena*. A large bloom of *Euglena* occurred on August 17 in the upper part of the Miami River from above Miamisburg to below Middletown, a distance of about 20 miles. On that date the bacteria population and the B.O.D. were generally low. Before and after August 13 the *Euglena* population dropped, and the chemical and bacteriological curves were variable. Another bloom occurred above Hamilton, 15 miles farther downstream, on September 1. This may possibly be the same bloom that was slowly traveling downstream, due to the low water and pooled condition of the river. This bloom was also accompanied by a low bacteriological population and B.O.D. values. Lesser blooms, likewise, were accompanied by low bacteria counts and B.O.D. values. However, this relationship was not consistent, as there were low B.O.D. and bacteriological values associated with low plankton counts.

It is interesting to note that the blooms of *Euglena* were generally found on the same dates that the peaks in the *Cryptomonas* curves occurred (Fig. 1).

Figure 3 shows that blooms of *Trachelomonas urcerola* occurred on June 27, August 31 and September 14 and *crebea* on August 4 and 31. The chart indicates that the high points in the urceolate curve correspond to a bacteria count of between 1,000 and 2,000 and the peaks in the *crebea* curve agree with a somewhat lower bacteria population and B.O.D. values of about 4 p.p.m. which indicates a fairly high degree of pollution. A low plankton population, however, may be accompanied by either a low or high bacteria population and B.O.D. values.

In addition to the above species of plankton, it was thought interesting to plot the distribution of *Phacotus lenticularis,* which is widely distributed over the Ohio Basin and is found in large numbers in certain localities. The distribution of this species in the Miami River is shown in Fig. 2. Peaks occurred August 8 at Cleves; September 15, above Middletown; August 17 to September 14, above Franklin and lesser blooms occurred below and above Miamisburg from August 17 to September 14. There seems to be an inverse ratio between the bacteria and plankton at all stations except Cleves and below Miamisburg where the curves vary in the same direction.

Discussion

In general, there seems to be an inverse relationship between the numbers of *Chrysococcus, Cryptomonas* and the coli-aerogenes group of bacteria and the B.O.D. However, no relationship exists between the population of *Euglena, Trachelomonas* or *Phacotus* and the bacteria and B.O.D. values. The blooms of *Euglena* were usually accompanied by low bacteria and B.O.D. figures. There are many cases where low bacterial numbers are not associated with high algae populations.

The peaks in the *Trachelomonas* curves correspond to a bacteria count between 1,000 and 2,000 and B.O.D. values between 2 and 4 p.p.m.

which indicates fairly heavy pollution. The population of *Phacotus* and the chemical and bacteriological data seem to vary inversely at most stations.

It has been shown (6) that a series of biological changes takes place in a stream below the source of heavy organic pollution, and that there is a general correlation between the total plankton volume and the sanitary condition of the stream. These changes fall into five well defined zones, if the pollution is of sufficient volume and if the sources of the waste along a stream are sufficiently separated so that the zones do not overlap. Immediately below the source of untreated sewage, the stream is characterized (not shown in the Miami River below Dayton) by a high bacteria population and high B.O.D. values. The number of species of plankton is small and the total volume is generally low, except in cases where a few species of ciliated protozoa are present in large numbers. The phytoplankton is usually scarce.

Farther downstream, as the substrate has been largely decomposed by bacterial action, the numbers of bacteria decrease and the B.O.D. drops rapidly. The total plankton volume shows a noticeable rise which consists largely of ciliated protozoa and colorless flagellates; a few chlorophyll-bearing flagellates such as *Euglena, Phacus, Lepocinclis, Chlamydomonas,* as well as small numbers of *Chrysococcus* and *Cryptomonas,* make their appearance. Still further downstream, where the sewage has been decomposed by the mixed bacteria population in the upper reaches of the stream, there is a further reduction in B.O.D. and coli-arogenes bacteria but there occurs a tremendous increase in the chlorophyll-bearing flagellates. Many species are represented and the total volume of plankton reaches the highest values in the stream. In this population of plankton there are usually large numbers of *Euglena, Trachelomonas, Phacotus, Chlamydomonas, Eudorina, Pandorina, Chrysococcus* and *Cryptomonas.*

Below this region of fertility the plankton volume as well as the bacteria and B.O.D. values decline sharply. The plankton is composed largely of *Chrysococcus, Cryptomonas* which can tolerate less concentrated mediums.

It must be realized, but it is often not considered in a biological survey, that a stream is not a static body of water, but is flowing at a more or less constant rate, and that the plankton is moving with a definite volume of water until that volume of water loses its identity by mixing with the waters farther downstream, or is diluted by tributaries. If a sample of water for a biological analysis is taken at the same station along a stream at the same time each day, a different volume of water is actually analyzed each time a sample is taken and, therefore, the data from that sample will tell but little, and that may be misleading, about the sanitary conditions at that station. It does, however, give a clear picture of the history of that particular volume of water in regard to the degree of upstream pollution. A bloom of *Euglena* or *Trachelomonas* may be found in a volume of water having a low bacterial count or B.O.D. value—indicative of clean water—(as from Franklin to Miamisburg on August 13) which, however, was heavily polluted upstream (at Dayton). The dense population of organisms may travel through a stretch of the river receiving no pollution, and still a biological analysis, based upon the numbers of *Euglena,* would show that the stream was polluted for miles along its course. The presence of these organisms, therefore, would give an erroneous picture of the stream. It would, however, definitely tell, that the volume of water containing the organisms, received organic pollution farther upstream. Likewise, a volume of clean water containing such genera as *Chrysococcus* and *Cryptomonas* and comparatively free of the "pollutional" forms, may pass through a source of pollution and travel quite a distance, before the water becomes sufficiently mixed with the pollutant and chemical changes occur which destroy the "clean" water forms. Sufficient time must also elapse to allow the "pollutional" forms to develop.

Summary

A comparison was made between the population of certain species of plankton algae and the chemical and bacteriological indices of the degree of organic pollution in a flowing stream. The results show that the presence of *Chrysococcus* and *Cryptomonas,* in large numbers indicate that the decomposition of the organic matter in the stream has been completed by natural processes and the stream may be considered clean. This, however, does not imply that the water (without treatment) is suitable for domestic use.

The presence of large numbers of *Euglena, Trachelomonas* and *Phacotus* indicates that the particular volume of water has been heavily polluted by organic matter farther upstream and that bacterial action has reduced the organic matter to available plant food, producing a rich medium.

The plankton population gives a better picture of the past history of a certain volume of water than it does of the sanitary condition of the stream at any definite location.

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THE OPERATOR'S CORNER

Conducted by W. H. WISELY, Executive Secretary*
Federation of Sewage Works Associations
Box 18 · · Urbana, Illinois

SABOTAGE IN SEWAGE WORKS

With the first accounts of the treacherous attacks on Hawaii, there came warnings to institute protective measures against sabotage in defense industries and essential public utilities. Undoubtedly, application of such measures in connection with sewage works has already been given consideration in most cities.

Exercise of calm, sound judgment in solving the problem is urged. Saboteurs would be most likely to give first attention to utilities which could be generally disrupted in their functions by damage at central points. At the same time, damage to some sewers and appurtenant structures could result in serious consequences and should be guarded against in every practical way. Except where public water supplies, oyster beds and sources of milk supply might be seriously affected, sabotage in connection with sewage treatment works would be of little military importance.

Planning of protective measures should be based on an analysis of vulnerable points in all facilities, probable effects of damage at each and methods of temporary and permanent repair in case of damage. Such studies will indicate where protection is most important and the extent to which measures would be practical. Many coastal cities have used similar studies as the foundation for planning protection against aerial bombing attacks.

In our consideration of this problem, it will be well to keep all information confidential and to avoid open discussion of details. The effectiveness of precautionary measures would be entirely defeated if vulnerable points were revealed. Don't give the saboteur ideas!

Every operator who has not already done so is urged to give careful study to the recommendations of Warren J. Scott in his paper "Operation of Sewerage Systems and Sewage Treatment Works from the Standpoint of National Defense," which was published in the November, 1941 issue of *this Journal.* Mr. Scott's suggestions are founded on logic and good judgment.

Be prepared and alert but use common sense!

* Also Engineer-Manager, Urbana and Champaign Sanitary District.

SEWER MAINTENANCE ARTICLE DEFERRED

To permit publication of several excellent operation papers presented at the Federation's Second Annual Convention last October, it has been necessary to again postpone the article "Experience in Sewer Maintenance" which had been previously announced for this issue. We shall be very glad to have contributions from anyone wishing to contribute to the article—now intended to be carried in the March issue.

SYMPOSIUM ON PLANT OPERATION AND CONTROL *

Leader: C. C. Larson

Springfield, Ill.

STANDARDS AND CRITERIA OF SEWAGE PLANT OPERATION

By Charles Gilman Hyde

Professor of Sanitary Engineering, University of California, Berkeley, California

General Considerations.—The fundamental principles of good design, as related to sewage treatment and disposal, demand:

(1) that the effluent of any plant shall meet all sanitary and esthetic requirements of the local situation;
(2) that the procedure shall be accomplished at the lowest reasonable cost.

It is obvious that the natural opportunities for ultimate disposal, whatever they are, should be fully capitalized. To rationalize all of the factors involved and to obtain the most satisfactory solution of any given problem may and usually does call for careful study and sound judgment. This is particularly true in view of the fact that designs are commonly, and very properly, made for a relatively remote "tomorrow," rather than for an immediately present "today." The future, whatever it is, must be forecasted with respect to sewage quantities, to sewage composition, to the volume and character of the ultimate diluting waters, if any, and to the use of such waters for domestic and industrial supply, for shellfish culture, and for recreation of all sorts: boating, fishing, bathing, and the like.

In the adequate and proper solution of the problem of sewage treatment and ultimate disposal, there are two categories of criteria or standards which require consideration and fulfillment. They may be defined as follows:

(1) those which determine the nature or type, and the desirable or essential extent of the treatment of the sewage;

* Presented at the Second Annual National Convention, Federation of Sewage Works Associations, Hotel Pennsylvania, New York City, Friday, October 10, 1941.

(2) those which determine the degree of compliance with the established standards of performance on the part of the treatment plant in its operation.

Analysis of Criteria Defining Nature and Extent of Sewage Treatment.—In the first named category of criteria or standards, *i.e.*, those which determine the necessary type and extent of sewage treatment for any given set of local conditions, are comprised, among other factors, the volume of the receiving waters and their capacity to innocuously dispose of sewage and sewage effluents. This capacity must be reckoned in terms measurable by routine observations or tests in treatment plant operation. It must recognize the circumstances of use of the receiving waters for all legitimate purposes.

The best single yard-stick for the determination of the capacity of diluting waters to satisfactorily dispose of sewage or treated effluents is the total weight of dissolved oxygen therein, either that which is presently available, or that which is acquired through surface absorption and through yield from plankton growths subsequent to receiving the contribution of sewage.

However, it is to be recognized that the oxygen supply in the receiving waters is not the only factor in the successful disposal by dilution of sewage or treated effluents. There are other controlling factors of significant importance. The entire list would comprehend at least the following:

(1) An adequate volume of diluting water.
(2) A sufficient supply of dissolved oxygen.
(3) Current velocities in the receiving waters sufficiently great to prevent the formation of sludge banks.
(4) Currents of proper direction, off-shore or along shore, which will not tend to carry the diluted sewage or effluent on to beaches or toward shallow waters.
(5) An adequate depth of diluting water in which to thoroughly diffuse the sewage or effluent; or, if depth is limited, then multiple outlets may be required to restrict the volume of sewage discharged at any point, *i.e.*, by any single outlet, to such quantity as can be satisfactorily diffused in the depth which is available.
(6) An outfall location sufficiently remote from recreational shores, shellfish layings, water supply intakes, etc., to insure the complete destruction of disease-producing organisms before the once-polluted waters can reach such locations; or, in lieu thereof, the disinfection of the sewage or treated effluent.
(7) The absence of floating material, including grease and the sleek resulting therefrom.
(8) The absence of excessive discoloration where such a condition would be obnoxious.

In arid regions inland watercourses may be virtually dry throughout protracted periods. The antithesis is an ocean shore with practically unlimited volumes of diluting waters. In the former case the highest and most effective form of treatment may be demanded. In the latter instance the extent of treatment required may be little or nothing; or, again, it may be considerable if neighborhood recreational and other interests are to be safeguarded, or if the cost of deep, remote outfalls is prohibitive. The salvage of the sewage for direct utilization represents, of course, a special case ordinarily demanding the highest and most refined processes of treatment yielding a clear, stable and disinfected end product.

In summary, it may be said that the proper type and extent of sewage treatment are determined by the presence or absence of favorable conditions as related to the above stated factors controlling successful disposal by dilution, and by the use to which the receiving waters are put.

Analysis of Criteria Defining Operational Compliance.—The load imposed by any treatment plant upon the means of ultimate disposal of the effluent, as by dilution, can be computed if the quantity and characteristics of such effluent are known. Obviously, if that load exceeds the capacity of the receiving waters to satisfactorily destroy the evidence and fact of pollution to such extent as local conditions require, then the load must be lightened by better and more effective treatment. Satisfaction with respect to such ultimate disposal always implies an adequate plant and its proper operation. The nature and extent of treatment, therefore, may be such as to redeem, conserve, or even promote, as the case may be, the sanitary and esthetic conditions of the receiving waters.

The old adage "The proof of the pudding is in the eating thereof" may be terribly trite but it is also terribly true. Nature soon proclaims any sins of commission in the field of stream pollution. But the appearance of the receiving waters, while important, is not conclusive. There must be other tests to determine compliance on the part of a sewage treatment plant with the requirements of local conditions.

The laboratory tests capable of determining such compliance are: (1) bio-chemical oxygen demand; (2) suspended solids or turbidity; (3) grease; (4) chlorine demand; (5) residual chlorine; (6) *E. coli.* Where the local conditions require pre-treatment (partial treatment) only, the first three determinations may be sufficient to determine positive compliance. Where disinfection is necessary, the last three should be added.

For any set of local conditions as related to the ultimate disposal of sewage or sewage effluents, it is manifest that standards of performance of the treatment plant can and should be established in terms of both quantity and quality since both, taken together, determine the load which will be placed upon the means of ultimate disposal. The means of ultimate disposal may be simple dilution or it may be utilization. In the former case there may be every range in environmental condition from an ocean shore to a dry river bed; from waters of little or no utility to those employed for domestic and industrial water supply, for all sorts of recreational purposes, or for shell fish culture. In the latter case (utilization), the effluent may be used for irrigation, park beautification, industrial purposes, and the like.

Many examples in American experience can be cited to illustrate both good and bad practice with reference to sewage treatment and ultimate disposal. Where good conditions prevail under difficult environmental situations it can be assumed with assurance that standards of operational performance have been carefully devised to meet the existing situation and that the plant operations are consistently in compliance with such standards.

Discussion of Paper by Charles Gilman Hyde

Dr. Rudolfs: Should streams be used to supplement sewage treatment? If so, what standards apply?

Prof. Hyde: We propose to use San Francisco Bay for reasonable loading.

Dr. Hatfield: If the stream is used to its capacity for receiving sewage effluent, industrial wastes will later overload it. A residual capacity should therefore be retained for this contingency. I am in favor of complete treatment.

Dr. Symons: Should Buffalo and Detroit consider B.O.D. or bacterial reduction as the basis of plant efficiency? The Buffalo effluent lowered the dissolved oxygen in the Niagara River 0.3 p.p.m. The *B. Coli* reduction in the river was from 24,000 to 7 per ml. In the International Boundary standards 500 *B. Coli* are allowed.

Mr. Wallace (Detroit): We allow a 40,000 *Coli* index in our plant effluent.

Mr. Enslow: I agree with Abel Wolman's paper which he presented at the Chicago meeting—the degree of treatment depends upon the need, economy and common sense judgment.

Mr. Scott: We prefer to use stream assets of purification to supplement the treatment plant's work.

Mr. Lee (Florida): We want an effluent with 1 p.p.m. residual chlorine.

Mr. Klassen (Illinois): If too much reliance is placed on the power of the stream to complete purification, operation of the sewage works may be slighted. We require ample and adequate treatment to meet all stream conditions, with some factor of safety.

Dr. Mohlman: It is rather illogical to discuss stream standards unless we differentiate between the use of the water for water supply and bathing as contrasted with use in which only prevention of nuisance is required. In the first case, bacterial standards are paramount, in the second, the oxygen balance. The type and degree of treatment of sewage are determined by these requirements.

Mr. Moses: The Pennsylvania standards for stream condition are well known. We classify streams in three classes of purity, and do not require excessive treatment of sewage beyond the standards set for the stream into which the effluent is discharged.

BIOLOGICAL FILTERS

By M. W. Tatlock

Superintendent, Sewage Treatment Works, Dayton, Ohio

I have a new job. I have been employed to supervise the operation of sewage treatment plants using biologic filters for secondary treatment. What must I know in order to successfully meet all the requirements of the position? My information should be found in the answer to these questions. What is to be treated? What are biologic filters? What life inhabits them? How do they operate? I shall look about for the answers.

What is to be Treated?

I find that there are underground pipes reaching out from the treatment plant to every home and industry in the city, and that through these pipes there will be delivered to the plant a relatively dilute water mixture of all the waste materials from the household and industry, which is called sewage. I find that the greater proportion of these waste materials is organic matter, and that it may be carried in suspension, in solution, or in such a finely divided state as to be considered colloidal in character. I find that sewage is naturally infested with saprophytic micro-organisms and pathogenic organisms discharged by persons suffering from certain infectious diseases, such as typhoid or dysentery, and that upon its arrival at the treatment plant it will become populated with untold numbers of additional organisms, and that the stream receiving the treated sewage will add the seed of its indigenous flora and fauna.

What are Biologic Filters?

I well remember the little stream near my boyhood home, alongside which a tomato canning plant was built. Immediately below the plant the stream was black and stagnant, the odors were foul, the fish died, but at the next highway crossing there were no evidences of this pollution. "Nature Unincorporated" had done her work. Why shouldn't I think of the sewage treatment plant as that long stream stretch contracted into some limited space, bounded by masonry walls within which exactly the same processes will take place as took place in that stream? I learn that the purification in the stream was done by biologic processes, that the destruction and removal of the organic wastes were brought about by the life activities of countless micro-organisms that, in their struggles to survive and reproduce their kind, had to have food and oxygen. The stream furnished the oxygen and the waste materials were the food. The organic wastes in the sewage will be a rich food supply, but the required oxygen must be applied by some outside source. From all these facts I have decided that the biologic filters, which I am to operate, must be that portion of the treatment plant which was built as a place of residence for those micro-organisms which will pay their rent by converting the objectionable organic wastes of the sewage into gases, mineral matter and other relatively stable substances.

I find that biologic filters are beds of sand, gravel, slag, stone, ceramics or other inert materials which will furnish a large surface upon which the biologic life may fix itself and develop a jelly-like zooglea which functions as a purification zone. The type of organism changes with the depth into the filter. In the upper strata those organisms will predominate which attack proteins and amino acids with the liberation of ammonia and hydrogen sulfide. There will also be decomposition of carbohydrates with the release of acids. These end-products will furnish the food upon which the organisms of intermediate depths thrive. The lower depths nourish the nitrifying and sulfur-oxidizing organisms.

I hope the designer of these filters has kept in mind that the success or failure of his venture will be measured more by how well he builded to furnish sufficient food and oxygen than by what I can do after operation begins. I find them called by many names, and they are all said to work; there are contact beds, intermittent sand filters, trickling filters for high or low rates, single-stage and multiple-stage filters, and more recently I learn that there are bio-filters, aero-filters, accelo-filters, and maybe there are others of which I have not heard. I find that regardless of the name by which the filter is called it must have its own design characteristics, determined by the type of sewage to be treated and the degree of treatment required, and that if successful operation is to be expected these design requirements must be recognized by both the designers and the operators. Basically the filter will remove the B.O.D. if the organic matter of the sewage is brought into contact with the flora on the filter media, in the presence of an abundance of oxygen.

Organisms Present

I must be the boss if I am to successfully operate these biologic filters, so maybe I should know something about the biologic workers which inhabit them. I find that I must expect them in numbers beyond human comprehension; that the principal and most numerous workers will be the filamentous and unicellular bacteria, which will have no green pigmentation, which will reproduce very rapidly, and that I may expect from one to ten million in every milliliter of sewage. I find that these creatures live either singly or in groups, that they secrete some gel-like material which coalesces to form that zoogleal slime on trickling filter media, and that they also generate substances known as enzymes which act as catalysts in hastening or causing chemical reactions, or causing hydrolysis of many fats or sugars.

Next to the bacteria, the protozoans will probably be the most abundant and important organisms, and that one group of the protozoans—the ciliates—will feed upon the bacteria, thus causing a constant renewal of bacterial growth. The presence of ciliates in the active filter slime should be a valuable index of its condition.

There will be filamentous chlorophylless plants called fungi, more closely related to the bacteria than the protozoa and less abundant than the protozoa. They are different from both bacteria and protozoa because the filaments are visible to the naked eye in the form of "sheep tail" growths wherever sewage contamination exists. These creatures derive their energy from the oxidation of organic substances; they can utilize carbohydrates; they can decompose proteins; and in trickling filters they form an extensive network which probably serves as a binder for the film on the media.

The greenish-brown color found on the topmost surface of the trickling filter will probably be algae, a low form of photosynthetic pigmented plants which give off oxygen in the waters where they grow.

There will also be many other classes of organisms; worms and insect larvae, rotifers and crustaceans, aquatic earthworms, sludge worms (*Tubifex* and *Limnodrilus*), a small moth-like fly (*Psychoda*), and the small wriggling water springtail (*Achorutes viaticus*).

Although my workers are normal inhabitants of sewage and will establish themselves spontaneously, they will require some time in a new plant to establish themselves permanently, fix their zoogleal film surfaces and give the final efficiency of treatment to be expected. I find this is called a breaking-in or ripening period, which will be shorter in summer than winter, and during this period I shall expect the effluent to become progressively better until normal operation is fully established.

My problem must resolve itself into finding and maintaining an environment which will favor and stimulate the activities of the desirable forms and, at the same time, eliminate or arrest the activities of any undesirable forms of biologic life.

Operation

I must operate what has been designed and built, whatever its name, but I must also acquaint myself with the design characteristics. I find that successful operation is more difficult to obtain if such factors as water-tight walls and bottoms; single units or multiple units; adequate underdrainage and ventilation; sound, properly graded and sized media; sufficient depth; adequate dosing and distribution have not been considered. In every plant there should be adequate provision for the removal of primary sludge before filtration and secondary sludge, the end products of biologic life, after filtration. If the above factors have not been incorporated in the filters I will encounter operating difficulties.

The absence of adequate primary treatment will cause the clogging of filter nozzles on trickling filters or the distribution troughs on sand filters, and the accumulation of sewage solids may clog the filter media and cause pooling, which will result in septic conditions in the lower portions of the bed because of the exclusion of air.

If the filter walls are not water-tight the filters cannot be flooded for *Psychoda* control. Tight walls will also obstruct the entrance and egress of the flies. They also assist ventilation and keep out cold winds.

Multiple units will insure adequate treatment when it becomes necessary to make repairs on some portion of the plant. They also permit only a portion of the area to be idle during flooding for fly control.

The underdrainage system serves two purposes: (1) it collects each filter effluent and delivers it into the main drain to the humus tanks and, (2) it is the lower end of the passage for air, either upward or downward through the filter. The first purpose requires that these drains be self-cleaning because the effluent carries all the flocculated solids unloaded from the filter. The second purpose requires that the drains be completely open to the air. The underdrains serving each filter subdivision should be provided with a valve so that it may be closed off for flooding in fly control.

The choice of filter material will usually be that available in the locality. It must be weather-resistant and strong enough to support its own weight without failure. It must not decay and it must not float when the filter is flooded for fly control. Smaller sized media will provide increased contact surface but it also reduces the size of individual voids and offers greater resistance to air flow and unloading. The adequacy of primary treatment and the depth of the filter are two factors which should have been considered in choosing the grading and placing of the media.

Filter depths vary from three feet to ten feet and it seems that the percentage reduction of impurities per unit depth of bed is fairly constant until some limiting depth is reached, which depends upon the rate of sewage application. The recent developments in the use of multiple stage filtration and biofiltration indicate the adequacy of shallow filters. Relatively deep, narrow filters are said to be better for aero-filters than wide, shallow ones, and accelo-filters should be five to six feet in depth, although shallower depths may be used under certain conditions. It seems that filter depth is a design characteristic to be determined by the type of filter selected to do the desired work.

Adequate distribution of the sewage can be controlled by keeping the system clean, but the dosing rates will depend upon the type of filtration employed and whether recirculation is incorporated into the general plan. There still seems to be merit in both the older standard rates of application with intermittent operation of dosing equipment as well as the newer developments of multiple-stage, high rate and recirculation designs and operation.

At some time in the operation of every filter there is an unloading and discharge into the effluent of the accumulated residues left from the operation of the biologic workers. Provision must be made to remove this material from the effluent. This is done in the final, or secondary, settling tanks.

I find that after due consideration has been given to all the above factors that there are still other factors to which attention must be turned. There are such problems as clogged nozzles or distribution system, odor control, filter sloughing, surface ponding and the filter fly.

The cleaning of clogged nozzles or distribution system will be a part of daily operating routine. If provision has not been made for adequate screening ahead of the filters it may be possible to provide some relief myself.

Anything clean and fresh does not smell. I shall hope for a fresh sewage to treat, and if it should be stale or septic maybe provisions can be worked out for preaeration, dilution with recirculated effluent, or chemical treatment with chlorine or iron salts.

The sloughing of filters has never been completely under control. It used to happen regularly, sometimes in the spring and again in the fall. Now, high-rate operation and the recirculation of filter effluent both seem to induce continuous unloading. There are also indications that complete sloughing may be expected if the pH becomes either too high or too low.

Surface ponding may be caused by the disintegration of the filter media or poor placing of the media, but I am the operator—not the designer. I have learned that the filter may become clogged with heavy grit deposits, by industrial wastes or chemicals, and by the accumulation of coarse sewage solids. I must, therefore, maintain all grit removal equipment in perfect condition, and know the industries of the community in order to avoid the possibility of having to remove, wash, screen and replace the filtering material. I find that chlorine will destroy fungus growths on the filter bed, which cause ponding, and that anything I can do to promote the activities of the water springtail will also materially assist in this work.

The filter fly (*Psychoda*) must be the real pest and greatest problem of the operator. I have found nothing good, said or written, about this inhabitant of a filter. Since it lives and multiples very rapidly, it has to have food and energy, so I shall assume that it destroys some organic matter in the sewage. Although it is called a fly, it doesn't fly far; if found any great distance from the filter it has been carried there by the wind. It can be combatted by heavy chlorination, but the best remedy seems to be to flood the filter on a time schedule which drowns the fly in its larva stage. One advantage claimed for high-rate operation is that fly-breeding is definitely discouraged.

Expected Efficiency

If I am a perfect host to all the biologic life to be found in the filter, if I can encourage the activities of the desirable ones and discourage the undesirable ones, if I can investigate, anticipate and prevent such undesirable factors as sloughing, ponding and odor, if I can control the flies, I may expect to operate these biologic filters with a reasonable degree of success and I may expect an efficiency of from 80–95 per cent as measured by B.O.D. removal, from 70 to 92 per cent of the suspended solids, and from 90 to 95 per cent of the normal sewage bacteria, and if I am fortunate enough to find unlimited finances for operation I am led to believe that any desired degree of complete treatment is possible by some combination of recirculation and high-rate treatment.

I know I shall enjoy my new job because it is a challenge to my best efforts. It appears to be a question of the survival of the fittest, and I expect to prove myself the most fit. Such is the operation of biologic filters.

DISCUSSION OF PAPER BY M. W. TATLOCK

H. HEUKELEKIAN: The larvae and worms in the filter seem to prevent choking of the bed.

DR. RUDOLFS: Regardless of the type of filter, Mr. Tatlock gives us the idea that the "bugs" are all the same and work alike. Is this true or even possible? The larvae are not drowned by flooding but are simply washed out and distributed in the stream.

F. W. JONES: The filter reduces the sludge solids to a limited degree. Filters are important in the cycle sewage—organisms—fish—man.

SANDERSON (Albany): Do you get higher purification when reaching design load or at 25 per cent? It takes one month for a biofilter to ripen and there seems to be better purification as the load is increased.

MR. ENSLOW: From all the results I have seen the minimum B.O.D. for a standard trickling filter seems to be 25 p.p.m. (This remark was discussed by several men who stated that 11–15 p.p.m. B.O.D. was not uncommon—that is, from the secondary settling tank of a trickling filter.)

MR. TATLOCK (In answer to Sanderson's question): The filters work best at design capacity.

PROF. FAIR: We should separate the functions of a filter into two phases—solids and liquid. In the low-rate filter, solids are accumulated in the filter and held there for biolysis and partial digestion. In the high-rate filter, the flocculated solids are not held in the filter medium for self-digestion, but are removed and digested in tanks. This is a more logical and efficient procedure.

MR. LANPHEAR: We find that our trickling filter effluent is best during September and October. The season of the year has a lot to do with it.

OPERATION OF SLUDGE DIGESTION UNITS

BY GUY E. GRIFFIN

First Lieutenant, Quartermaster Corps (On leave of absence from Public Works Department, Greenwich, Conn.)

In the request for this paper I was asked to cover the operation of all types of sludge digestion units, with both fixed and floating covers.

That is quite a bit of territory to cover in the few minutes allotted to me but it does seem quite appropriate to start this discussion with a short story on the starting of operation of several sludge digestion units with which the speaker has had some experience. The problems involved, and method of handling were different in each case.

The construction of a sludge digestion tank (Fig. 1) at Old Greenwich, Conn., in 1932 was part of the revision of an overloaded plant. While the construction work was going on we were working on an accumulation of sludge in large septic tanks which did not seem to want to digest. Some of this sludge although very odorous had to be pumped to the sludge drying beds in order to have any capacity for sedimentation. Some of the rest of it we recirculated with a portable diaphragm pump, adding milk of lime as we did so. In this manner we obtained a quantity of fairly well digested sludge which we felt would be satisfactory for seeding the digestion tank. Since plenty of this sludge was available, the digestion tank was filled more than half full. Computations indicated that the expected daily quantity of raw sludge solids would be about 3 per cent of the total solids in the seeding sludge. The seeding sludge contained about 3 per cent solids of which the volatile solids were about 60 per cent.

FIG. 1.—Digestion tank of sewage treatment plant, Old Greenwich, Conn.

The temperature of the tank contents was raised in a period of a few days to about 80° F. by the use of coal in a combination coal and gas boiler and maintained at that point. During the first four weeks of operation the gas production averaged 772 cu. ft. per day from about 3,000 population but increased to an average of 3,250 cu. ft. per day for the next four-week period. Of considerable interest in connection with the early operation of this digestion tank was that it was found possible to pump to the tank considerable quantities of practically raw sludge which had accumulated over a period of about three months in one of the septic tanks. Only once was there any indication of foaming and that subsided quickly with a decrease in the quantity of septic tank material pumped. No lime was used during the first eight months operation of this digestion tank. Digested sludge drawn to the beds at the end of two months contained 6 per cent solids, 45 per cent volatile solids and the pH was 7.1. From these results we may consider that the tank was in balanced operation in two months.

The digestion tank at the Grass Island plant in Greenwich was also built as part of the revision of another overloaded plant. The old shallow Imhoff tanks, built in 1918, foamed vigorously at times but by careful maintenance of high sludge levels and judicious use of lime produced a fairly well digested sludge.

The new digestion tank was put into operation on January 7, 1939, by seeding with all of the sludge that was in the Imhoff tanks.

Computations indicated that in this case the expected daily additions of raw solids would amount to about 15 per cent by weight of the solids in the seeding sludge. Sufficient liquor was also pumped into the tank to float the cover, the inspection hand holes closed, and after about two hours the waste gas burner was lighted and continued to burn for two and one-half months while the heating boiler was being installed. During this time there was no heating of the digestion tank, the temperature of the digesting sludge averaged 48° F. yet the gas production varied from 1,000 to 1,500 cu. ft. per day from the seeding sludge and daily additions of 1,000 to 1,500 cu. ft. of raw sludge. The seeding sludge contained 53 per cent and the raw sludge from 75 to 80 per cent volatile solids.

When heat became available, produced by the sludge gas and auxiliary city gas burned in the same burner under one boiler, the temperature of the digesting sludge was raised gradually, about two degrees per day to 85° F. Gas production increased to slightly over 10,000 cu. ft. per day or approximately 1 cu. ft. per capita. There was no foaming and no great surge of gas production as might have been expected from the accumulation of raw sludge. Lime was used during the first five 4-week operating periods to maintain the pH at 6.8 to 7.0 and required from 250 lb. to 3,000 lb. per 4-week period. During the next six 4-week periods of summer no lime was required but since then regular additions averaging about 50 lb. per day have been used.

The first digested sludge drawn to the drying beds was in May 29, 1939, almost five months after starting the tank and two and one-half months after starting to heat it. This digested sludge contained 5.4 per cent solids of which 53.2 per cent was volatile matter. The pH was 7.0. From then on digested sludge was drawn about once a month except during the winter months.

Perhaps a unique feature of the construction of the Grass Island digestion tank was the provision of two rings of piping attached to the under side of the floating cover, with ½ inch nozzles pointing upward. The piping terminated above the cover with valves and hose connections through which supernatant liquor has been pumped at a pressure of about 30 lb. per sq. in. twice a week to effectively soften the scum and keep it moist. The depth of the scum has varied from one to three feet.

In accordance with the requirements of the New York State Health Dept. for cleaning up the Hudson River, the city of Ossining, N. Y., built a plain sedimentation-separate sludge digestion type of sewage treatment plant which was put into operation on May 3, 1940 (Fig. 2).

Two digestion tanks were provided with a total capacity of 35,300 cu. ft. for a design population of 14,000 or 2.52 cu. ft. per capita. Both tanks were provided with floating covers and piping was so arranged that the tanks could be operated in parallel or in series.

It was decided to start the tanks in series as primary and secondary digester without seeding. Both tanks were filled with sewage sufficient to float the covers. The temperature in the primary tank was raised in a few days to about 85° F. and raw sludge pumped to it daily. Lime was added regularly with the raw sludge to keep the pH at about 7.0 This required 3,750, 3,650 and 3,175 lb., respectively, for each of the first three 4-week periods after which the requirement dropped to as little as 150 lb. for the seventh 4-week period.

The first appreciable gas production was on May 24, when 800 cu. ft. were recorded only 21 days after starting. It was possible to light the waste gas burner on May 31 or 28 days after starting. The sludge gas was turned on to the boiler on June 9 and on June 18 a gas production of 4,000 cu. ft. was sufficient to carry the heating load without any auxil-

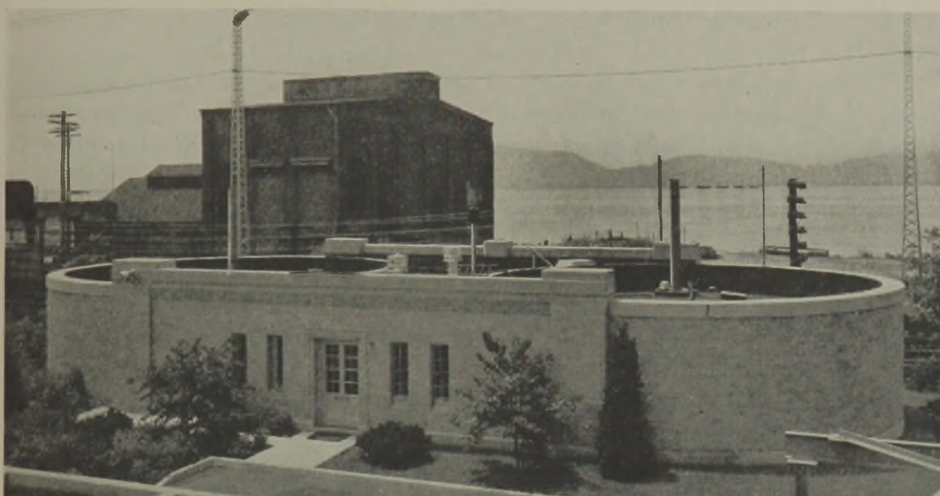

FIG. 2.—Sludge digestion tanks, Ossining, N. Y.

iary city gas which had been used to heat the tank. This was 46 days after the first raw sludge was pumped to the tanks.

Digesting sludge was allowed to accumulate in the primary tank to about mid-depth before any was transferred to the secondary tank. The first transfer was on August 12 followed thereafter by transfers about every fifteen days. The first digested sludge was drawn to the drying bed on Sept. 19—139 days after starting digestion.

Decanting liquor from the primary was transferred daily to the secondary digester and from there to the sedimentation tanks as necessary.

The temperature of the sludge in the primary tank averaged about 88° F. during the first nine 4-week operating periods. No hot water was pumped through the heating coils of the secondary digester yet the temperature was maintained at a fairly uniform point by the decanted liquor. Even in December and January it did not fall below 70° F.

A surprising amount of gas was collected from the secondary digester. It varied from six to sixteen per cent of the total production.

Computations indicate that for the first nine 4-week operating periods the gas production averaged 7.3 cu. ft. of gas per pound of volatile solids added or 8.3 cu. ft. per pound of volatile solids digested. These figures appear to be low compared to results at other places.

Darien.—At Darien, Conn., part of a new sewerage system was put into operation on April 1, a new sewage treatment plant started operating on May 25, and the remainder of the sewerage system completing twenty-four miles of sewers went into operation on August 9, 1940.

The sewage treatment plant of the plain sedimentation separate sludge digestion type treated an average flow of 154,000 gallons per day during the first 4-week operating period from an estimated population of 750 persons which increased in a year to an average flow of 254,000 gallons per day for the thirteenth 4-week period from an estimated connected population of 2,500 persons.

In view of the small plant loading at the start, it was decided to start the digestion tank without seeding and without heat.

There was scarcely enough sludge during the first few weeks of operation to pump to the digester even once a week. This increased, however, as new house connections were made at the rate of 30 to 70 connections per month.

Lime was used to maintain the pH of the digestion tank contents near the neutral point. The required quantity varied from 100 to 950 lb. per 4-week period and totaled 6,750 lb. for 52 weeks. No appreciable amount of gas was produced during the first three 4-week operating periods. During the fourth period gas production increased from zero to 900 and averaged 432 cu. ft. per day. The rate of production remained about the same for the next two operating periods then nearly doubled and showed a gradual increase to the end of the operating year. The gas production during the thirteenth operating period averaged slightly over 3,000 cu. ft. per day. The temperature of the digestion tank contents averaged about 60° F. and was maintained at this point after sufficient gas was being produced to do so. Several interesting things were noted in connection with the operation of this digestion tank. Very little scum accumulated under the floating cover during the first year of operation. Analysis of raw sludge showed a very low volatile solids content of 56 per cent yet it had a typical offensive raw sludge odor. Digested sludge drawn to the beds for the first time on May 25, 1941, had a volatile content of 35 per cent showing a reduction in volatile solids of 57.5 per cent. The low volatile content was probably due to the presence of considerable fine silt which found its way into the new sewers during construction.

Summary.—Thus four sludge digestion units were successfully started into operation under different conditions and procedure.

One was started with both seeding material and immediate heating.

The second was seeded but no heat was available for several weeks of cold weather.

The third unit was started without seeding but with immediate heating to optimum temperature.

The fourth unit with very light loading was started without either seeding or heating.

Lime was used as necessary to control pH in each of the units.

Acknowledgment.—Revisions of the Old Greenwich and Grass Island plants were designed by Metcalf and Eddy of Boston. The Ossining plant was designed by James Harding of N. Y. and the Darien plant was designed by Sanborn and Bogert of New York.

Mr. Joseph Doman of Greenwich, Conn., assisted in assembling some of the data for this paper.

TABLE I.—*Digestion Tank Data*

Plant	Size of Tank		Capacity, Cu. Ft.	Tributary Population	Cu. Ft. per Capita
	Diameter, Ft.	Side Wall Depth, Ft.			
Old Greenwich, Conn.	20	22	6,632	3,000	2.31
Grass Island Greenwich, Conn.	30	25	18,853	10,000	1.88
Ossining, N. Y.	34	19	35,300*	14,000†	2.52†
Darien, Conn.	30	18	13,433	2,500‡	5.37‡

* In 2 tanks. † Design figure. ‡ As of May 24, 1941.

DISCUSSION OF PAPER BY GUY E. GRIFFIN

MR. DONALDSON: Lime was used in starting the Imhoff tanks at New Castle but it was added to the sewage flow rather than through the slots.

QUESTION: When is it necessary to seed in starting a new sludge digestion tank?

LARSON: We didn't seed our tanks but we started during the summer.

QUESTION: Is there any difference in scum formation in seeded and unseeded tanks?

ANSWER: There is no difference.

DR. RUDOLFS: Seeding is preferable in that it accelerates digestion.

MR. LANPHEAR: It isn't necessary to seed an Imhoff tank.

MR. KASS (N. Y. C.): A plant can be started without seeding. At Coney Island the flow was gradually increased from 23 m.g.d. to 45 m.g.d. The operation was satisfactory.

DR. HATFIELD: How good is the volatile acids determination in controlling sludge digestion?

MR. BLOODGOOD: Determination is helpful.

MR. TATLOCK: After the explosion at Dayton our tanks foamed for 18 months after restarting and seeding.

MR. MARTIN (Green Bay): Tatlock states that volatile acids were not determined on the sludge. This is important if there are industrial wastes in the sewage.

MR. COBURN: What is the danger limit for volatile acids?

MR. KRAUS: At 2,000 p.p.m. the digestion stops. At Pekin, 3,000 p.p.m. were found to be all right.

Dr. Rudolfs: The range seems to be from 1,000 to 10,000 p.p.m. It is hard to set a definite limit for all sludges—depends upon characteristics of the sewage. Digestion seems to be good at 1,000 and poor at 10,000 p.p.m.

COLD WEATHER OPERATION

By A. E. Berry

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Sewerage systems, constructed on a part of this continent, have been confronted with the problem of operation in cold weather. Temperatures and duration of cold periods vary a good deal. In Canada, where the observations for this paper were made, extremes of temperatures are encountered. The Province of Ontario, occupying the central part of the Dominion, possesses a substantial number of sewerage systems, with treatment plants of different kinds. Southern Ontario has a relatively mild winter, while in the north this season is long and the temperatures are severe. For these conditions the designer and the operator must plan accordingly.

As a comparison with certain parts of the United States, it may be said that central Ontario only infrequently experiences temperatures of 10 to 20 degrees below zero. In Northern Ontario figures of 50 below zero are not uncommon. Difficulties in treatment plants may occur from both short and protracted cold spells. The latter are greater in number in Northern Canada.

Cold weather problems are created by freezing temperatures, by snowfall, and by sleet. The former necessitates protection against frost action in the sewers and in the disposal works. Snowfall and sleet interfere with operation and with sludge handling.

Sewer Systems.—Inasmuch as the problems of sewage treatment cannot be segregated entirely from conditions encountered in the sewers some consideration of these is justified. The depth at which the sewers are laid will have some effect.

Experience in cold weather indicates that in most cases the sewers need not be laid at any great depth. The warmth of the sewage tends to prevent freezing. Sewers need not be laid to the same depth as watermains. In parts of Canada it has been found necessary to lay watermains as deep as 7 or 8 feet. A good deal depends on whether the street above the main is much travelled, or whether the snow is removed regularly. An undisturbed covering of snow has a very considerable insulating value, permitting the main or sewer to be closer to the surface. Sewers as shallow as 2 feet in undisturbed land have been found to be free from frost action, but in general a depth of 5 feet or even more is preferable, and is in more general acceptance.

Sewer Connections.—Connections to sanitary sewers sometimes give trouble through freezing. This is particularly true when the connection is close to a manhole having a vented cover. Under these circumstances the cold air passing in through the manhole and up the connection tends to freeze the liquid and cause choking. This can be overcome either by changing the location of the connection or by reducing the vent spaces in the manhole cover. The use of covers with no openings has advantages also in reducing odors from these manholes, which at times are obnoxious.

Water and Sewer Mains in Same Trench.—Construction of water and sewer mains in the same trench has been practised to an appreciable extent in Canada, particularly in rock formations. The procedure is not generally recommended because of difficulties in settlement and in making repairs or connections, but the economy is sufficient to justify this in places. Little trouble has been experienced in these cases since the watermain is laid above the sewer, and the depth is sufficient to protect against freezing.

Frost sometimes causes interference with manholes. On paved streets frost may heave the road, and unless the manholes rise to the same extent a traffic bump occurs. This has been corrected by the insertion of planks cut to shape over the manhole. Similarly the condensation of vapor from a vented manhole may cause ruts and bumps.

Storm Sewers.—Storm sewers are more subject to cold weather difficulties than sanitary mains. Heavy snowfall also enters into this problem. Catch basins are in use in most of these systems but in some centres these have been omitted, and the pavement is drained by a pipe direct to the storm main. Few difficulties have been encountered under these conditions and less work has been involved in maintenance.

Catch Basins.—Where catch basins are in use considerable difficulty results from snow accumulations and freezing. Sudden thaws or rains may occur when these basins are choked. Thawing of these catch pits by the use of a portable steam boiler mounted on a truck has proven efficient. A further improvement has resulted from placing the catch basins closer together, about 200 ft., and thus necessitating a shorter flow for the surface water.

Catch basins should be built fairly deep. If they are constructed too small or too shallow they are more likely to freeze and in some cases the basin may heave sufficiently to interfere with the entrance of water. In central Ontario it has been found necessary to have these basins at least 5 ft. deep. In colder areas greater depths would be recommended. The entrance of slush has little effect in thawing any ice which may be in the basin.

The use of sanitary sewers for the disposal of surplus snow has been practised in many centres. It increases the flow of sewage at the plant as well as augmenting the amount of grit to be handled there. Chemical treatment of streets in Canada for snow removal has not been followed extensively, but cinders and sand add additional loads to the disposal works, and may account for higher figures for suspended solids at those times.

On the favorable side there is an advantage in cold weather for sewer operation. This tends to minimize septic action in sewage, and it reaches the plant in a fresher condition.

Sewage Treatment Plants.—In the treatment of sewage the effects of cold weather are marked with advantages and disadvantages. On the favorable side may be listed the fresher condition of the sewage, and particularly the reduction in odor control and stream pollution.

Occasions for odor complaints in winter are greatly reduced both about the plant and along the receiving waters. This might be taken to justify, under certain circumstances, a reduction in treatment during that period. Such is the case where drinking water supplies are not concerned, but where only the sanitary condition of the stream is involved. The design of plants to take advantage of this situation would be justified to a greater extent were it not for the fact that municipal councils are inclined to consider that a reduction in treatment for the winter can be equally successful in summer, especially when funds are difficult to obtain.

Retardation of bacterial action in water during cold weather tends to carry the effluent farther downstream before oxidation or destruction takes place. This can be both an advantage and a disadvantage. When the receiving water is frozen over, as in a river, lack of oxygen supply from the air has caused offensive conditions where the water was used for watering stock or for other agricultural or industrial purposes. Such circumstances would require a continued high degree of treatment in winter as in summer.

Observations indicate a higher ammonia content in sewage-laden waters in winter than in summer. The plate counts and colon figures are also affected by the weather, and they create varying loads on filtration plants.

Cold weather operation calls for precautions both in the design and in the maintenance of treatment plants. In the colder areas it would be difficult to operate a plant which had been designed for warmer climates. Wide variations in temperature in Canada have made necessary designs which will meet these conditions to an extent probably not encountered elsewhere.

Covering of Plants.—Under what conditions should a disposal plant be housed? There is a growing trend in this direction for certain parts of the plant as a means of odor control. This practice has proven efficacious. Glass as well as other materials have been used. Covering also aids in operation during extreme cold periods. While average winter temperatures may affect the operation, it is the extremely low temperatures which cause greater difficulties, even though they may not persist for long periods.

In the central and southern parts of Ontario, tanks containing sewage either for sedimentation or for activation have been operated successfully without covers. The same holds for most of Canada except in the more northern parts where it has been customary to cover most of the plant.

Covering of sewage disposal works is not required merely by the fact that the sewage will freeze, but rather because of certain parts on which ice may form and cause interference. This includes air lines, entrance and outlet channels, equipment, sludge handling, etc.

Activated sludge plants have been used extensively in Ontario where secondary treatment was necessary. A limited number of sprinkling filters are now in use, and these are all covered. Some of these were operated in the past without covering. While ice formed on the beds to a considerable extent, they were able to operate successfully. In the covered plants there has not been occasion for supplying artificial heat.

Difficulties Encountered.—In the difficulties experienced at some of the plants in Canada both primary and secondary works are involved. In some clarifiers operating in the open, freezing of the surface of the water has occurred. This is overcome by frequent breaking and manual removal. The months of February and March give most trouble in the north. In another uncovered plant it has been found that when the temperature drops as low as 20 degrees below zero the channels delivering sewage to the settling tanks freeze, because of the smaller volume of water exposed. This can be overcome by close attention of the operator during these abnormal periods. Lubrication of exposed parts of operating mechanism is needed. Changing of oil every 2,000 hours has given satisfaction, the oil used being S.A.E. 30.

Activated Sludge Plants.—In activated sludge plants the blowing and piping of air may give trouble. Blowers with water seals were less satisfactory than piston compressors, in which there is some heating of the air. In all air lines the problem of overcoming condensation and freezing is an acute one. If moisture is introduced by the blower it may result in difficulties in the pipes or in the valves.

Air lines have been placed both above and below the sewage in the aeration tanks. Many piston compressors are in use, and these have given only a minimum of trouble in freezing of the air lines. In a number of the uncovered plants in Ontario the air lines are not submerged, and are thus more convenient for valve operation. Needle point valves freeze easily if moisture is present. Placing these valves and pipes away from direct wind action is important. When placed above the sewage but sheltered from the wind they are able to withstand severe temperatures without freezing. Submergence of valves and air lines in the sewage eliminates this problem.

The use of clarifiers with the drive mechanism operating on a track may be subject to attacks by sleet. A number of these have been operating for some time in Ontario with but little difficulty except of a temporary nature. Sand on the track seems to overcome this problem.

Sludge Handling.—Sludge handling is hampered by cold weather. Efforts have been made to avoid this by covering the drying bed, by heating, and by other means. Where mechanical dewatering is in use there is little occasion for difficulty.

Sludge Digestion.—Sludge digestion can be carried on rapidly only when the tanks are adequately heated. Heat losses in winter are minimized by earth insulation. In some instances, particularly for small plants, the sludge tank has not been heated, but has been regarded as a storage unit only. When the volume has been increased accordingly this has been successful and has overcome the necessity of trying to dry sludge in cold weather.

The seals on the pressure relief on one digester with a fixed cover has consisted of "Prestone" anti-freeze. This has been effective until the anti-freeze is diluted with water of condensation.

Insulation is an efficient method of protection of a plant where water of condensation is likely to form. It prevents undue condensation in the gas chamber and gas piping from digestion tanks.

While mechanical dewatering of sludge has established its position there are many plants in which drying on beds is the practice. Winter drying in open beds is impracticable in most parts of Canada, and the early attempts to do this proved unsuccessful. This has been overcome in several ways, including covering the beds, heating, winter storage, and by removal in the liquid state. Glass-covered beds are used in several places, some with heat and some without. Where no heat is added the cake is allowed to freeze, broken up, and drawn away. Where large quantities are not involved this has proven suitable. In heated beds the coils have given way in many places to unit heaters which create currents by blowing the hot air against the sludge. These beds require a minimum of heat, as little attempt is made to keep them much above freezing. The action of the sun on the glass reduces the period of heating to a minimum. Observations made on some heated drying beds with digested sludge point to a drying period of about twice as great in the winter as in summer.

In recent years a number of plants in Ontario have utilized a contract service for removing the sludge in the wet state. This is spread on the land for fertilizer in both winter and summer. The sludge is concentrated by settling, and is removed in closed tank trucks of 5 to 10 yards capacity. The cost of this has been within the competitive range of other methods, averaging about 40 to 50 cents per cubic yard. Much depends on the solids content. In this way difficulties are avoided since the sludge is neither digested nor dried.

Dewatered sludge taken in steel cars to the point of disposal may freeze on the car. This problem has been met in one plant by blowing warm air into the car on its return to the building and during loading. Sludge handling in winter may be difficult but the acceptance of modern methods has done much to ease this problem.

Pumping Station.—Pumping stations either at the disposal works or elsewhere are likely to be injuriously affected by cold weather. Condensation may be marked and corrosion will be augmented. Thorough insulation of the tanks and buildings will reduce this, and yearly painting of all exposed metal will be justified.

The possibility of difficulties in cold weather operation of sewage treatment plants in Canada is ever present. By foreseeing this in the design it has been possible to avoid the more serious ones. A variety of measures may be taken to guard against the effects of extreme weather. Even though these attacks may be of short duration they may cause considerable inconvenience in the plant which is unprepared.

Discussion of Paper by A. E. Berry

Mr. Schroepfer: On November 11, 1940, we had such a blizzard that we couldn't get out or get to the plant for a couple of days. For just such an emergency we had canned goods and cots at the plant and they came in mighty handy.

Note: The additional papers in this symposium, "Sewage Treatment Works Operation Records," by Roy S. Lanphear, and "Screenings Handling and Disposal," by Wellington Donaldson, will be published in the March issue.

BARK FROM THE DAILY LOG

January 1—Celebrated New Year's Day by reversing the flow through the Imhoff tanks—a semi-annual operation. Sludge soundings do not indicate that flow reversal is necessary to maintain a uniform sludge level in the tanks but it does result in equalizing the heavy gas vent scum accumulation over the entire tank length.

Just thinking of that scum problem brings on a headache, but, after all, headaches are quite in vogue on this of all days!

January 3—One of the operators reported today that he had slipped from a ladder three days ago and that his back has been bothering him ever since. Does everyone experience trouble in getting accidents reported when they happen so that prompt insurance claims can be filed?

January 6—Began manual removal of scum from Imhoff tank gas vents. The dry material on top is shovelled off and hauled directly to the sludge stock pile, thus conserving drying bed area. The wet portion is pumped to the drying beds. (A total of 31,400 pounds of dry solids were removed in this fashion during this month as compared to raw solids received amounting to 75,600 pounds for the month.)

N. Y. A. labor on this work kept the operating budget from suffering unduly.

January 7—Installed a new disc, disc-bolt, hinge and hinge-pin in the check valve on the discharge line of Pump Number 2. Functions just like new—slam and all!

January 8—At the regular monthly meeting of the Board, a 66-page report including an inventory of the present loads, efficiencies and limiting capacities of each plant unit with recommendations for a 10-year program of expansion, was presented to the Trustees. Without complete operation and laboratory data, particularly during the past three years, the study would have been impossible.

The report revealed overloads in primary sedimentation, sludge digestion and final sedimentation; liberal trickling filter capacity; and reasonably adequate sludge bed area. Construction of additional units and modernization of certain equipment were recommended in the order of greatest need as available funds permit.

Many plants built 10 to 20 years ago are now reaching their design loads and it is suggested that studies such as this, made before conditions become critical, afford a sound basis for planning extensions as they are needed.

January 13—For the past month, Pump Number 2 has been aspiring to retirement in much the same manner as did the famous "One Horse Shay." Four weeks ago an attempt was made to correct a sort of "rheumatism" in the top thrust bearing, and it was taken down again a few days later to improve the shaft alignment (quite difficult with the obsolete, fixed coupling) and to add a collar and felt washer at the top sleeve bearing to retain lubricant at that point. Today the lower sleeve bearing became very hot and it was found that the bearing bushing had loosened in the housing and "frozen" to the shaft.

This veteran item of equipment has ended 17 years of yeoman service Rated at 3.5 m.g.d capacity, it has pumped about ten billion gallons of sewage in its life-time—approximately half the flow which has passed through the secondary treatment units in that period. Replacement of the pump had been planned soon because recent studies had indicated operation at poor efficiency.

January 14—To New York City to attend the annual meetings of the Federation's Board of Control, the New York State Sewage Works Association and the American Society of Civil Engineers. Witnessed the rebirth of a stronger and more useful Federation and came away with lots of enthusiasm and an appointment as one of the "wet-nurses" to assist it through an extremely important transitional stage.

January 21—Ordered 65 feet of 36-inch rubber floor matting today to protect the freshly painted floor in the main pump room. Costing only $1.00 per yard, this protection is considered well worth the money, aside from the improved appearance of the room.

January 22—Truly an epic day! It marks the end of that lagoon cleaning job that has been responsible for so much sweat and swearing for the past three months. More than 850 cubic yards of humus were removed at no cost to the District other than supervision of N. Y. A. labor by regular plant personnel. In the spring, we shall level up the bottom and restore the unit to service as a supplement to the final sedimentation tank to "polish" the final effluent.

January 25—Took down the wire mesh screens at the dosing tanks for replacement of the quarter-inch mesh. These screens are suspended at the dosing tank inlet weirs to retain extraneous objects which would clog filter nozzles.

January 26—The father of one of the N. Y. A. boys phoned this morning to ascertain the youth's whereabouts. Hadn't been home (or here at the plant) for three days. The lad was located later in the day—in jail!

The boys aren't all like that, however.

January 29—Replaced several more sections of dosing tank air piping and installed plugged tees at one bend to facilitate routine flushing. Also placed union in a straight pipe so that future repairs will be more convenient.

February 4—Dame Experience, that school marm than whom there is no better teacher, has just taught us a lesson in her own inimitable way. The Imhoff tanks have recently executed their annual winter maneuver of turning upside down, i.e., much of the bottom sludge rose into the gas vents. In an effort to release gas, the vents on two tanks have been hosed down and now we find that the bottom sludge level is above the slots! As a result, keeping the flow channels skimmed free of floating solids will be a major project until enough sludge can be drawn to the drying beds or will rise back into the vents to clear the slots.

The next time this happens, we shall try to release the gas by opening only a narrow strip along the vent walls in the hope that the pressure of gas beneath the scum will keep a few gas "boils" continuously open. (Our gas vent sprays cannot be used in this season because of ice formation.)

February 5—Recommended to the Board of Trustees that replacement of the late 3.5 pump be accomplished by completely rebuilding from the original casing as a basis. Because of the cramped condition in the dry well, provision of an entirely new pump would require piping changes which would make this solution cost about $400 more than the one recommended. The rebuilt pump will be new and modern except for the shell, having a new flexible shaft, impeller, bearing housing, motor coupling and other parts. The efficiency will be increased from 56 per cent to 74 per cent by the changes.

The recommendation was accepted and a contract closed with the pump manufacturer.

February 10—Completed taking down the pump to be rebuilt and shipped the casing to the factory.

February 15—Completed arrangements with the University of Illinois to take a large quantity of dried sludge for building up lawns around new buildings. The industrial cars used in cleaning the beds will be dumped directly into University trucks, saving us $10.50 per day for truck hire.

February 17—Imhoff tanks back to normal again after upset earlier this month. Question: How do we keep 'em that way with no more available drying bed space?

February 20—Cleaned and inspected the 30 horse-power motor which will be retained in service on the rebuilt 3.5 m.g.d. pump. Bearings and insulation good. Only work required is replacement of the wiring terminals.

February 22—Washington's Birthday—cherry trees! O yes, today we went over the plant grounds and park with the landscape architect, planning replacements for the trees destroyed in the Armistice Day storm and for some of the shrubbery. The list includes a few evergreens at the Screen House, a row of six moline elms along the East Drive and a honeysuckle screen border at the storage yard.

Could spring, like prosperity, be just around the corner?

February 24—E. J. "Jack" Beatty, of the Wisconsin State Board of Health, called today to take over the books and records accompanying the office of Secretary-Treasurer of the Central States Sewage Works Association. Yielded the records to Jack with mingled feelings—regret at giving up this enjoyable work with its many pleasant associations and pleasure at seeing it placed in such capable hands.

February 27—With gas vent scum eight to ten feet thick in two of the Imhoff tanks, we replaced the sprays yesterday. Despite the heavy accumulation, the sprays effectively soften the scum and permit gas to escape freely. Using them only two hours daily when the air temperature is above freezing.

February 28—Addressed the local Lion's Club on the topic, "Progress and Trends in Stream Sanitation."

Well, they didn't **all** go to sleep!

MAINTENANCE OF SEWAGE TREATMENT PLANT EQUIPMENT *

By Roy C. Hageman

Plant Mechanical Engineer, Southwest Treatment Works, The Sanitary District of Chicago

The term maintenance, in its engineering sense, may be defined as the art of economically keeping plant equipment, structures, and facilities in condition to fulfill adequately the purposes for which they were intended.

The word art in this definition is construed to mean skill acquired through experience, study and practice.

Ideal maintenance consists of that work necessary to prevent the need for repairs with emphasis on the prevention of emergency, or unscheduled, repairs. This ideal is probably never entirely attainable. To approach it closely may not be economical. It is a problem of management to determine the proper relation between the costs of the various factors which enter into the successful performance of any plant.

Maintenance of any type of plant or equipment cannot be divorced from other factors of equal importance. These other factors are: design, manufacture, construction, and operation. Above each of these is another factor, management.

It is obvious that the finest kind of maintenance cannot produce satisfactory results if the basic design is faulty. This statement is also true if the manufacturer has used faulty materials or parts or has permitted inferior workmanship. It follows that plant or equipment which

* Presented at the Illinois Conference of Sewage Works Operators, Springfield, Ill., Dec. 2, 1941.

has been improperly installed or operated cannot be economically maintained.

Just as these statements are true, the reverse is true. Incompetence on the part of the maintenance department will not permit satisfactory results no matter how excellent have been the experience, knowledge, and skill entering into the other factors.

A modern, highly mechanized sewage disposal works presents many problems not encountered in any other industry. In general, however, it may be stated that the basic problems and much of the equipment have their counterparts in such industrial and public utility works as: chemical plants, paper manufacturing plants, steel works, and central power stations. All require a high degree of skill on the part of the administrative, engineering, and working personnel.

In this presentation we will consider the effect of design, manufacture, construction, and operation upon maintenance, with particular reference to the maintenance of equipment. We will also consider management of maintenance with its accompanying organization, the establishment of procedures, records, cost accounting, and other functions of management.

Design

Maintenance costs must first be considered in the design. The designer must balance the cost of maintenance as represented by local conditions of labor, accessibility and cost of parts and supplies, and outage of equipment against the cost of design, manufacture, construction, and operation.

The Centrifugal Sewage Pump.—The centrifugal sewage pump is an example familiar to all sewage works operators. Some of the difficulties which may be encountered may be listed as follows: failure of bearings, excessive wear of shafts where they pass through stuffing boxes, excessive packing replacements, excessive wear of rings, casing plates, and impellers, and clogging.

It is obviously desirable that the pump operate with the lowest possible power requirements. Efficiency, however, cannot be measured only in terms of output divided by input. The designer must also give proper weight to the cost of clearing clogged pumps and other difficulties which may be aggravated by the attempt to obtain high mechanical efficiencies.

If local labor costs are high, the designer is justified in using materials of higher quality and longer life. Under certain labor conditions, the designer should incorporate features which permit removal of impellers without the need for disconnecting the piping.

Bearings are less apt to fail when selected liberally. It is obviously necessary that leakage from stuffing boxes or that water from any source be prevented from entering bearings. Undersized shafts or an unbalanced impeller can cause whipping of the shaft with resulting impact loads on the bearings and consequently shorter bearing life. Whipping of the shaft also makes stuffing box maintenance costly.

Most sewage pumps are now fitted with renewable sleeves where the shafts pass through the stuffing boxes. Such sleeves may be made of bronze or of a stainless, alloy steel hardened sufficiently to give relatively long life. This prevents the need for replacing the entire shaft. However, in order to reduce wear to a minimum, other considerations must be taken into account.

The location of the lantern, or water seal, ring is important. If the stuffing box is to prevent outward leakage of sewage, the lantern ring should be located toward the bottom of the stuffing box with one or two rings of packing between the lantern and the bottom of the stuffing box. If the pressure to be sealed is approximately atmospheric, the lantern can best be located so that an equal number of packing rings are on either side. If the stuffing box is to prevent air from entering the pump, most of the packing rings should be between the lantern and the bottom of the stuffing box with only one or two packing rings outside the lantern.

The most common and satisfactory seal is provided by piping clear water to the lantern ring. If the lantern is located as just described and the gland properly pulled up, a slight dripping of clear water at the gland indicates adequate sealing and minimum wear.

Screen Cleaners.—Screens and screen cleaning mechanisms are also familiar to all sewage works operators. In general, it may be stated that the simpler the design the more satisfactory will be the performance.

As in all governmental work, the designer is faced with a difficult choice. He may write specifications requiring certain performance, thus leaving the details of design to the manufacturer of the equipment. Or, he may completely design the equipment and call for bids on the basis of the detailed design. The Sanitary District of Chicago, in the case of screen cleaners, has chosen the latter method (Fig. 1).

The design chosen is of the endless chain type. The cleaning device, or rake, is secured to the conveyor chains which, in turn, are carried on sprockets. The chains are of such size that stretching is not a serious problem. Where possible, the motor and speed reducer are coupled to the head shaft and overhung. Thus, when the head shaft is adjusted to tighten the conveyor chains, the driving mechanism is automatically adjusted so there is no need to devote additional time to this operation.

Having selected the size of the conveyor chains, the selection of sprockets, shafting, bearings, speed reduction mechanism, and the motor follow. The entire mechanism, including the motor, is proportioned in strength to the conveyor chain. This eliminates the need for complicating the mechanism with shear pin devices and prevents the possibility of any part of the entire mechanism from ever being over stressed. It is a physical impossibility for loads greater than intended to be exerted on any part of the mechanism.

Since debris will occasionally lodge in the screen and cleaning device in such manner that the mechanism will stall, it is necessary that the motor be protected. This is accomplished with ordinary thermal relays which will trip out the motor switch before the motor has been damaged. Since the motor, even when stalled, cannot exert sufficient torque to damage the remainder of the mechanism, the thermal relay is for protection of the motor only.

It is rather obvious that the life of a screen cleaner, or any other mechanism, is dependent upon the amount of load carried and upon the total time of operation. Thus, it is desirable that the total time of operation be held to a minimum.

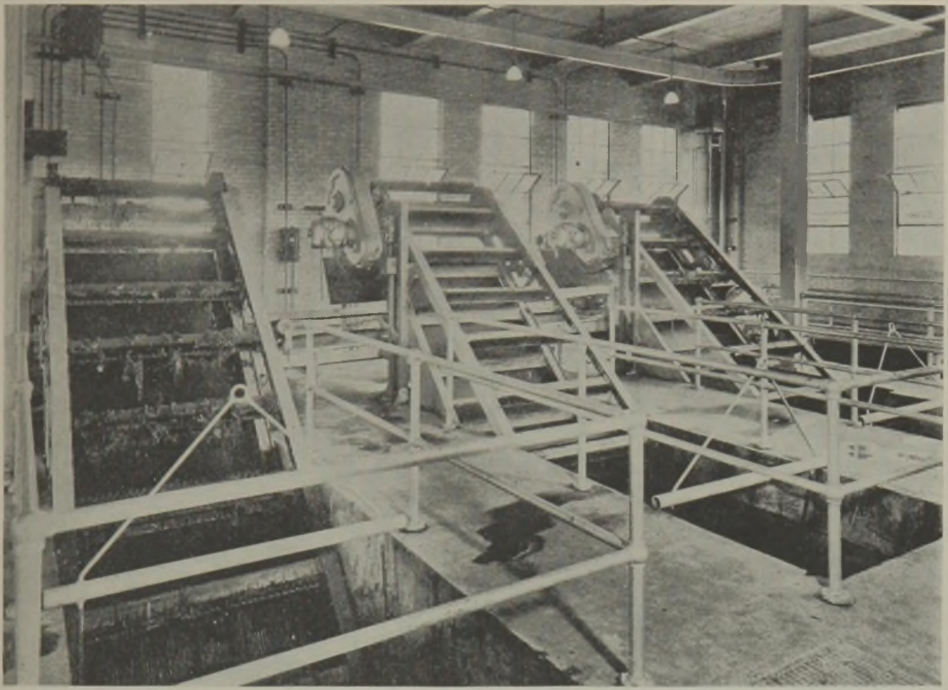

FIG. 1.—Sludge screens, Southwest Sewage Treatment Works, showing driving mechanism mounted on head shaft.

At the North Side Sewage Treatment Works, a head loss device is used to start and stop the screen cleaner as required. This device is an air-purged, differential switch of the diaphragm type. When sufficient debris has lodged on the screen to increase the loss of head to a predetermined amount, the switch operates to start the screen cleaner. When the debris has been removed, the switch operates to stop the screen cleaner. This device has proved to be extremely satisfactory.

A time switch may also be used satisfactorily to operate the cleaning mechanism for a predetermined period out of each hour. This type of switch, of course, must be manually adjustable so that the cleaner may be operated during a greater period when large quantities of screenings are being accumulated.

Human ingenuity has not yet been able to devise a screen and a cleaning mechanism which are never subject to repair. Another feature of design, however, facilitates repairs when repairs are necessary. This feature permits the entire screen and its cleaning mechanism to be bodily elevated, or rotated, from the chamber without the need for perfectly tight stop logs or gates.

Comments on Design.—In these ways, the designer, by giving proper consideration to maintenance, may incorporate in the design of the original screen and screen cleaning mechanism certain features which have a bearing on the costs of maintenance. Fundamental principles of machine design may be applied to all equipment in such manner that what may appear to be higher first cost is balanced by savings in maintenance costs.

Fig. 2.—Preliminary settling tanks, Southwest Sewage Treatment Works, showing individual driving mechanism for each collector.

Among the equipment and facilities to be found in a modern, highly mechanized sewage disposal plant may be listed the following, all of which must be considered by the designer from the viewpoint of maintenance costs in addition to all other considerations: sludge removal mechanisms, mixers, dryers, screw conveyors, elevators, belt conveyors, cyclone separators, precipitators, boilers, turbines, pumps, blowers, control systems, electrical generators, and speed reducers together with the required power piping, high and low pressure and process piping and ducts, and all electrical service (Figs. 2 and 3).

We frequently hear maintenance men refer to the need for rebuilding a machine in such manner that certain weaknesses in its design will be corrected. When such weaknesses are the result of improper design, manufacture, or construction the cost of rebuilding is not properly a charge against maintenance. The maintenance man is, in effect, usurping the field of one or more of the other contributors.

The work of providing equipment for sewage disposal plants, and particularly the large scale dewatering, drying, and disposal of sewage sludge by continuous, mechanical methods, is a relatively new field of

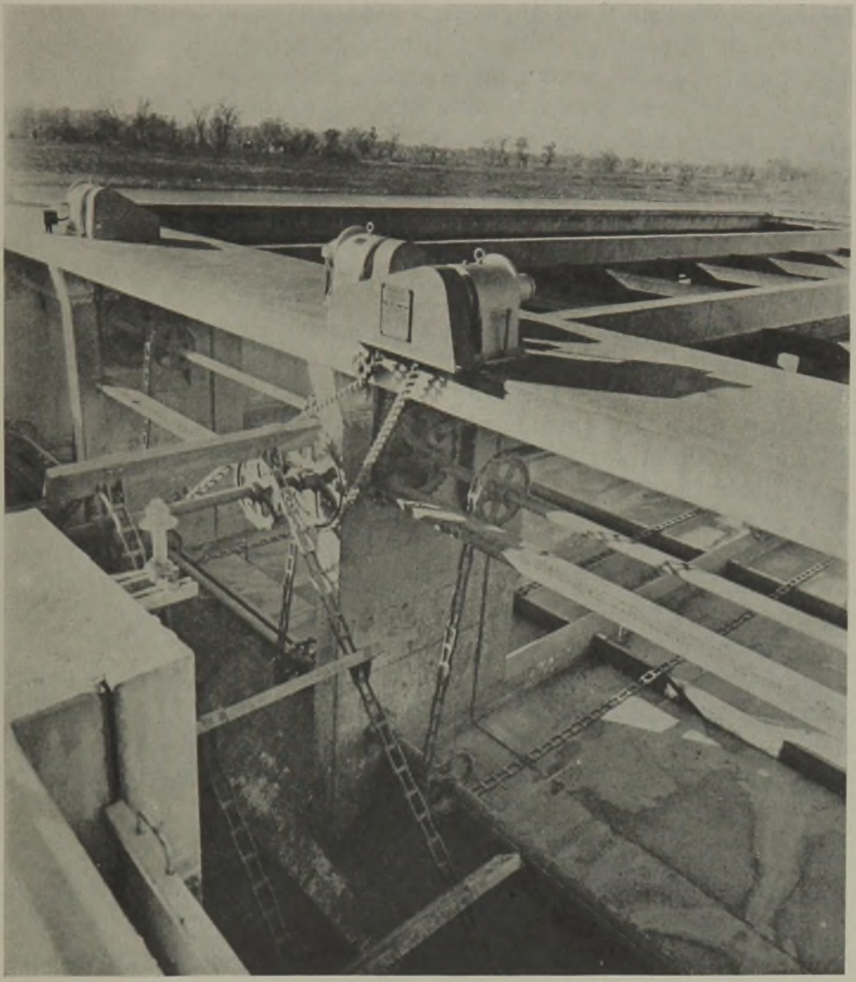

FIG. 3.—Preliminary settling tanks, Southwest Sewage Treatment Works, showing driving mechanism for main and cross collectors.

endeavour. In most other industries, the development and establishment of processes and equipment has taken place over a considerable period of years. Plants have been expanded bit by bit as demanded by business considerations. A sewage disposal plant, on the other hand, is built to satisfy immediately the requirements of an established community. Considering the newness of many of the processes and much of the work, the amount of progress that has been made is remarkable.

The pioneers who have contributed to all phases of these developments are deserving of great credit.

Circulating Fans.—At the Southwest Sewage Treatment Works there are problems which are not common to most other sewage or industrial works. One example should be of interest.

All sewage sludge contains grease, oil, and fat in some quantity. The packinghouses of Chicago, discharging sewage which has a relatively high percentage of these materials, have introduced a problem which was not foreseen, at least in its magnitude. This has resulted in loss of plant capacity and substantial maintenance costs viewed from the labor requirements as well as outage of equipment.

After concentration and dewatering, the sludge, or filter cake, is transported to the drying plant for the removal of the remaining water by evaporation. The filter cake, however, cannot be dried in its existing state without producing a sticky, gummy mass. Consequently, a sufficient quantity of previously dried sludge, called dry return, is worked into the filter cake to produce a mixture which can be successfully handled. This also benefits the process by breaking up the material to be dried into smaller particles, thus causing much greater surface area to be exposed to the drying medium. Since perfect mixing is almost impossible of attainment, some particles of dry sludge are carried through the mixer without being thoroughly moistened.

The discharge from the mixer is dropped into the hot tower, or drying tower, where it is exposed to a temperature varying up to about 1050 degrees Fahrenheit. The water content of the moist sludge prevents this material from becoming overheated. The dry particles, however, are raised in temperature to the point at which some of the grease, oil, and fat are distilled off in the form of a vapor.

Following the drying process is a cyclone separator which separates the dried sludge from the steam or vapor which has resulted from the evaporation of the water contained in the filter cake. The vapor distilled from the grease, oil, and fat is carried from the cyclone separator with the steam or vapor.

A circulating fan in the process draws the vapor from the cyclone separator. At this stage of the process, the temperature has been reduced from the hot tower value of 1050 degrees to about 300 degrees. At this lower temperature, the vapor is about ready to be converted from the gaseous to the liquid state.

The high velocity impingement of the vapor upon the fan blades causes a part of it to adhere to the blades of the fan in the form of an oil. This oil forms a bonding material which causes some of the very fine, powdery dried sludge which was not removed in the cyclone separator to adhere also to the fan blades. The result is that there is a gradual building up of this material upon the blades of the fan. The distribution is quite even and there is no immediate trouble. However, in from three to six weeks, sometimes less, the fan will become unbalanced. This is probably aggravated by some of the material being thrown off.

There has been no choice but to take that drying system out of service and laboriously clean and, if necessary, rebalance the fan. This work has represented a substantial item of maintenance cost both from the viewpoint of labor and from loss of production of the equipment.

A number of methods have been tried in attempts to prevent the accumulation of this material upon the fan blades. Among these methods have been: the introduction of abrasive materials such as fly ash during operation; the introduction of chemicals in an attempt to destroy the bond; and the alternate application of the maximum safe high temperature followed by rapid cooling. None of these remedies produced practicable results.

From other experiments, we do know that, if the blades of the fan could be held at a sufficiently high temperature, the bond would be destroyed and there would be no accumulation of material. The latest, and most promising, experiment has been along this line. An electrically heated blade has been installed on one fan. While this experiment is still in progress, it seems quite possible that a potentially practicable idea has been developed. To complete the data, the experiment must determine the minimum amount of power which is required to accomplish the necessary results.

It is a problem of management and design to balance the cost of designing, manufacturing, installing, operating, and maintaining heated fan blades in all fans against the cost of cleaning by hand and the cost due to outage of equipment.

Manufacture

The quality of the manufacturing has a decided bearing on the costs of maintenance. If the specifications are not in sufficient detail so that all bidding is on the basis of equal equipment, each manufacturer is compelled to figure the job close enough to have an opportunity to get the contract against competition. The result can quite likely be that faulty materials or inferior workmanship go into the equipment in order to make a profit on the contract. Or, the equipment furnished might be lighter in weight, less rugged, or have other unsatisfactory aspects viewed from the desire for low maintenance costs.

Rigid specifications on satisfactory design, materials, workmanship, and performance followed by competent inspection and testing of the equipment provide the best means of assuring adequate manufacture. This is true where equipment must be purchased through competitive bidding. Most manufacturers are anxious to see that their work complies with all contracts and specifications. From the manufacturer's viewpoint, it is less costly to make corrections in the shop than in the field.

Construction

The installation of equipment is usually the work and responsibility of the construction department. The equipment and its requirements must be taken into consideration in determining the degree of care to be taken in installation. A tool room lathe, for example, must be installed with the very highest degree of precision in order to prevent distortion. A steam-turbine driven generator must be aligned with only a very slight limit of error in order to prevent excessive maintenance. On the other hand, a much greater degree of error is permitted in the installation of the conveyor chain sprockets of a sludge removal mechanism.

To return to the centrifugal sewage pump, the maintenance costs will be high if, in the installation, the pump is twisted through distortion of the base plate. The suction and discharge piping must be connected and supported in such manner that no stresses are created in the pump housing above those for which it was designed.

There are many other examples. Welding in the field if not properly done or properly stress-relieved can increase the costs of maintenance. A floor drain may be located in a high spot instead of the floor being pitched toward the drain. The drain line may have been left with some concrete in it by a contractor. It is the responsibility of the construction department to see that contractors and workmen comply with all the requirements of drawings, specifications and contracts. It is further the responsibility of the construction department to call attention to alterations which may be required by changing conditions or which may be desirable in the light of newer experience.

Operation

Carelessness or incompetence on the part of operating men increases the cost of maintenance. The operator must be thoroughly schooled in the operating principles and in the care of the equipment for which he is responsible. He must also understand the purpose for which that equipment was installed so that he may recognize adequate performance.

Bearing failures, for example, are caused by too much lubrication as well as by too little lubrication. The selection of the type, quality, and quantity of lubricant must be made by the operating department giving consideration to the design and also to the manufacturer's and to the refiner's recommendations.

Probably most operators have caused a substantial repair job, at some time or other, by using a shear pin larger or stronger than the one originally provided.

In a pulverized-fuel fired furnace, the operator can increase maintenance costs by improperly adjusting the flame. Slagging is aggravated by improper adjustment of the distribution and amount of combustion air. Slagging, in turn, can cause leaky water screen tubes or blanked off boiler passes which require that the unit be taken out of service. The charges involve both those of the labor to perform the work and those due to outage of equipment.

Failure to recognize or to report minor difficulties can quite possibly result in larger repair or maintenance costs later. It is the responsibility of the operating department to see that performance is adequate. It is the further responsibility of the operating department to make such running repairs and inspections as can be made and to report promptly any deviations from normal performance.

Management of Maintenance

After plant equipment, structures, and facilities have been placed in operation, proper upkeep is the function of the maintenance department. Just as the designer must give heed to such considerations as the type and size of plant and equipment, availability of the required labor, repair parts, supplies, shop and other repair facilities, and safety, so must the manager of maintenance. From the viewpoint of economy and adequate performance, these considerations require the development, establishment, and use of procedures, records, and cost accounting. In addition, adequate performance requires the establishment of schedules of inspections, outages, and repairs at least to such extent that such scheduling is practicable.

There are, of course, other considerations in the management of maintenance. These considerations may be listed as follows:

Selection of the type and number of personnel.
Training of personnel.
Delegation of responsibility to assistants and supervisors.
Determination of methods of performing work.
Determination of spare parts and supplies to be stocked.
Selection and procurement of maintenance equipment and tools.
Establishment and enforcement of rules and regulations to assure the maximum of safety to personnel plant, and equipment.

We will concern ourselves here primarily with a discussion of procedures and records. We will follow this with a brief discussion of two or three of the other considerations. The magnitude of the total maintenance problem will determine the extent to which the procedure should be carried. Procedure may be taken to mean the orderly reporting of work to be done, the reviewing of the report by persons competent to pass judgment, and the authorization to the plant maintenance force to perform the work. The procedure must also provide for the inspection of the completed work and for the notification of all persons interested.

At the Southwest Sewage Treatment Works, the established procedure entails the filling in of printed forms of which there are three. These are: (1) Operator's Bad Order Report, (2) Work Request, and (3) Job Order. Each form has space for such typical information as: the name of the person to whom it is addressed, the date, the proper designation of equipment or structure, the exact location, the time by which the work must be completed, and the signature of the person filling in the form. The Work Request and Job Orders are numbered.

The Operator's Bad Order Report provides space for the description of the trouble. This should be as complete and as accurate as possible so that an accurate analysis can be made.

The Work Request is similar to the Bad Order except that it has to do primarily with improvements, alterations, or additions to plant or equipment. Space is provided in which the description of the work, or the results desired, are written. Where necessary, a sketch or drawing is attached.

The Job Order is the authority for the plant maintenance force to perform the work and it is filled out in triplicate. The original is filed in the Plant Office, the duplicate is retained by the man in direct charge of the maintenance forces, and the third copy is delivered to the man delegated to perform the work. The description written on a perfect job order, accompanied by sketches or drawings where necessary, provides all details required for the successful completion of the work. There should be no need for the workman to obtain additional verbal information. It should not be necessary, however, to incorporate instructions pertaining to the workman's skill in the pursuit of his trade or occupation. The Job Order contains space for entering the names and dates of assignments, date of completion, names of persons checking the work, and remarks. On the back of the original is space for entering the daily time record of each man engaged on that job. When completed, the triplicate is returned to the Plant Office where all information subsequent to the initial authorization is transcribed to the original. The original is then filed for record purposes. Thus, when filed in a readily accessible manner, the Job Order becomes the primary record of plant maintenance. This provides the management with a written record to add to its experience and knowledge. Among other things, it is extremely useful in predicting future requirements and this is one of the most important aspects of management.

Since it is obvious that records are of no value unless filed in an accessible manner, the filing system is important. For this reason, the Plant Code System, in use at the Southwest Sewage Treatment Works, was devised. This tool has been valuable in so many ways, that its plan may be well worth reviewing briefly.

This system divides the plant first into its main parts on the basis of function or purpose. There are some thirty of these primary divisions, each given a number. A few, chosen at random, are as follows:

(1) Main Sewage Pumps and Auxiliaries.
(5) Steam Generation and Auxiliaries.
(8) Sludge Drying Systems and Auxiliaries.
(10) Power Piping and Appurtenances.
(24) Aeration and Final Settling Tanks.
(28) Buildings and Structures.

Each of these main divisions is sub-divided into its essential components each of which is given a letter. For example, take Item 1, Main Sewage Pumps and Auxiliaries:

(1) Main Sewage Pumps and Auxiliaries
- (*A*) Steam Turbines.
- (*B*) Reduction Gears.
- (*C*) Pumps.
- (*D*) Lubrication System and Bearings.
- (*E*) Condensers and Auxiliaries.

Each of these sub-divisions is further classified into the components which past experience has indicated will provide adequate and desirable records. Each of these sub-divisions is given a number. For example, take 1–*C*, Pumps:

(1) Main Sewage Pumps and Auxiliaries
    (*C*) Pumps
        (1) Impellers.
        (2) Stuffing box shaft sleeves.
        (3) Wearing rings.
        (4) Packing.
        (5) Priming system.
        (6) Discharge valves.

Thus, every Job Order can be given its proper code identification and space is provided on each Job Order for the entering of this information at the time of initial authorization.

With this filing system, any desired information may be quickly located. For example, the manila folder 1–*C*–4 in the cabinet containing completed Job Orders will hold every completed Job Order authorizing packing of the main sewage pumps. A glance will determine the date on which the pump was packed, the kind of packing used, and the names of the men performing the work. Since a time record is kept of each Job Order, the cost of labor and material may be applied to each item of the code system. Thus, management can detect costs which are out of the ordinary.

The Plant Code System has been valuable in other ways. For example: when a boiler and its connected drying systems have been out of service for an extended period during which inspections, repairs, and miscellaneous maintenance work have been done. Since the code system lists every component part of the boilers and also of the drying systems, it provides a perfect list of items to be checked without the possibility of any being neglected or forgotten.

At the present time we are beginning the preparation of a Plant Safety Code. This will follow the general plan of the regular code system. Thus, when a mechanic receives a Job Order to perform work, the coding which appears on the Job Order will direct him to the Safety Code which will provide him with all instructions for his personnel safety as well as the safety of the equipment. For example, the safety code will require that the isolating switch be disengaged and properly tagged with a Hold Card before a workman enter a piece of equipment driven by an electric motor. The safety code will require that all firing equipment be properly isolated and tagged with Hold Cards before a workman may enter a furnace. In addition, the safety code will include such general items as the use of ladders, ropes, slings, and first aid.

There is an old adage that a good mechanic can work without perfect tools. It is true that a good mechanic can obtain results through makeshift methods. This, however, is not necessarily economical. It is a function of management to determine what types and quality of maintenance equipment and tools are required and then to procure them. Management must also determine the economical methods of performing work. The most costly method of cutting a hole in a piece of steel is by drilling followed by reaming and then honing. Where accuracy demands such precision, the cost is justified. However, frequently a hole produced by a cutting torch is adequate. If it is, more costly methods are not justified.

The amount of spare parts and supplies to be carried in stock is a difficult problem of management. If an adequate record system has been in effect for a sufficient length of time, this problem is considerably simplified. Otherwise, the only answer is to use the best judgment possible based upon experience and upon the availability of the materials believed to be required. Under present conditions, substitute or alternate materials and parts must frequently be used. For example, at the Southwest Sewage Treatment Works, the vacuum filters were originally fitted with Monel wire mesh for backing up the filter blanket and with Everdur or K-bronze wire for securing the blankets to the drums. None of these materials is now available for prompt delivery. Consequently, it has been necessary to experiment with other materials. The Monel wire mesh is being replaced with specially designed wood backing and it seems quite possible that the substitute material may prove to be more satisfactory and economical than the original. The wrapping wire is now copper with a coating of a thin, tough, insulating varnish. This also appears to promise very satisfactory results although a number of problems have had to be solved.

Summary

To summarize, it may be stated that the manager of maintenance is concerned with the contributions of all persons whose work enters into the completed whole. He is concerned with the design, manufacture, construction, and operation of plant and equipment as well as with its maintenance.

He is concerned with the skill and productivity of all persons who are directly under his supervision. He must direct and co-ordinate the efforts of these persons in such manner that economical and adequate performance of plant and equipment are attained.

To accomplish this end, his own skill, experience, and knowledge of basic engineering, of the work of all of the skilled and unskilled labor groups, and of management must be ever increasing.

INTERESTING EXTRACTS FROM OPERATION REPORTS

Springfield, Illinois (1940)

By C. C. Larson, *Chemist*

Log of Important Events

Jan.—The month of January was one of the coldest on record.

Jan. 25—The pressure relief well on Digestor No. 3 froze and forced sludge over into gas lines. Operator had put kerosene into well as instructed but had neglected to remove water!

Feb. 7—Digestor No. 1 foamed over edge of floating cover causing it to tilt and bind against the concrete wall of the tank.

Apr. 8—Power line feeding plant flashed across during electrical storm. Linemen made repairs after dark and accidentally reversed the phases. When we cut the plant in everything ran backwards. Very disconcerting!

Apr. 15—Drew first sludge to drying beds.

Apr. 17—Dewatered Dorr secondary settling tank and replaced carriage wheels supporting extension arms. These had been in service four years. Found the chains which support the counterweights almost worn out where they pass over the sheaves.

May—Five groups of students from Hospitals and the Junior College visited the plant during May.

June 18—Drew several beds of sludge using varying amounts of alum in order to accelerate drying.

July 9—Began drawing sludge from primary tanks every two hours to prevent activated sludge from going septic and rising to the surface.

July 26—Started a first-aid course for plant employees under the direction of the Red Cross. Course will run for ten weeks.

Aug. 20—In August the large sludge storage tank was emptied into a lagoon and the last seven feet of sludge was removed only with the greatest difficulty because it was very heavy and had set up into a stiff jelly. Sludge had been drawn regularly from this tank to the drying beds but the large volume in the bottom probably represented an accumulated excess from several years back.

After a prolonged period of bulking the activated sludge suddenly decided to settle out beautifully and for no apparent reason. Those bugs are certainly temperamental.

Sept. 7—Hot water coil in Digestor No. 5 developed a bad leak. Pumped the tank down and allowed it to stand for 15 days before going in. The coils carried a layer of scale about $\frac{3}{16}$ of an inch thick which was easily knocked off with a wooden mallet. The scale was quite porous in structure and from all appearances should serve as an excellent non-conductor of heat.

Sept. 13—Gas line from holder became clogged with foam and scum cutting off the engines.

Sept.—Virtually no rain fell during September.

Oct. 21—Thin layer of sludge rose to the surface of secondary settling tanks.

Nov. 16—Installed a new raw sludge pump. Worthington, centrifugal, five-inch. This replaces a Dayton-Dowd three-inch which has done heroic service for more than ten years.

Established a new record for gas production; 125,000 cubic feet.

Nov. 29—Took Digestor No. 3 out of service in order to remove scale from heat coils.

Summary of Operation Data

Item	1940 Average
Connected population	85,000
Meteorological data:	
Rainfall recorded	22.85 inches
Rainfall normal	36.45 inches
Mean air temperature	53.2 degrees F.
Sewage flow—average daily	6.9 m.g.d.
Per capita daily	81 gallons
Screenings removal—per m.g. treated	0.50 cu. ft.
Per capita per year	0.02 cu. ft.
Grit removal—per m.g. treated	0.83 cu. ft.
Per capita per year	0.03 cu. ft.
5-day B.O.D.:	
Raw sewage	203 p.p.m.
Primary effluent	151 p.p.m.
Removal—primary treatment	26%
Final effluent	13 p.p.m.
Removal—complete treatment	94%
Suspended solids:	
Raw sewage	199 p.p.m.
Primary effluent	123 p.p.m.
Removal—primary treatment	38%
Final effluent	10 p.p.m.
Removal—complete treatment	95%
Sludge digestion:	
Raw sludge quantity per m.g. sewage*	6,950 gallons
Solids content	3.78%
Volatile content	64.8%
Gas production (daily)	64,400 cu. ft.
Per capita daily	0.76 cu. ft.
Per pound volatile solids added	8.7 cu. ft.
Per pound volatile solids digested	16.8 cu. ft.
Gas analysis:	
Carbon dioxide	33.4%
Hydrogen	2.29%
Methane	64.6%
H_2S (gr. per 100 cu. ft.)	5.92 grains
B.T.U. net	593
B.T.U. gross	658
Digested sludge:	
Volatile matter reduction	52%
Solids content	9.07%
Volatile content	53.2%

* Mixture of primary and waste activated sludge.

Summary of Operation Data—Continued.

Item	1940 Average
Activated sludge:	
Mixed liquor—suspended solids	1,840 p.p.m.
Settleable solids (30 min.)	27%
Sludge index (Mohlman)	157
Return sludge	30%
Suspended solids	6,730 p.p.m.
Settleable solids (30 min.)	87%
Aeration period	7.1 hrs.
Applied air—per gallon sewage	0.84 cu. ft.
Per lb. 5-day B.O.D. removed	714 cu. ft.
Supplied by gas-driven blowers	91%
Operation costs:	
Per million gallons treated	$15.28
Per capita per year	$ 0.45

Minneapolis-St. Paul Sanitary District (1940)

By George J. Schroepfer, *Chief Engineer and Superintendent*

Civil Service and Pension Plan Considered

During the year, the Board of Trustees discussed the matter of civil service and pension systems for Sanitary District employees and the Chief Engineer and Executive Secretary were instructed to study these matters and to take them up with the Board. This was done and from time to time, the Board members discussed various methods under which a civil service system and a pension plan could be established. The consensus seemed to be that the Board should institute a merit rating system of some sort providing rules for employment and for discharge of employees for cause and establishing certain definite plans of promotion. The pension plan which seemed to find most favor with the Board members was that under which the District and employees would contribute in equal portions, the pension plan to be underwritten by an insurance company or companies. Details are being worked out for formal presentation to the Board of Trustees. The relatively few employees of the District and the highly specialized type of work for which there is no precedent in this vicinity make the working out of a merit rating system and a pension plan rather difficult. Study of these matters is being continued under authorization of the Board of Trustees.

Typhoid Inoculations for Employees

Continuing its policy of safeguarding, in so far as possible, the health of its Sanitary District employees, the Board of Trustees authorized re-inoculation of all employees against typhoid fever and paratyphoid. This work was done at the District's expense.

General Plant Operation

Screen and Grit Chambers.—During the year 1940, the quantity of screenings removed averaged 1.06 cubic feet per million gallons, and the quantity of grit 6.2 cubic feet per m.g. These are somewhat less than the quantities in 1939, which averaged 1.28 cubic feet of screenings and 8.8 cubic feet of grit per m.g. The reason for this reduction is largely due to the planned program of increasing grit chamber velocities to carry over into the subsequent processes larger quantities of fine, inert material to increase the concentration of solids removed from the settling tanks and to otherwise improve vacuum filtration. The average velocities during dry weather flows have been gradually increased from approximately 0.75 to 1.20 feet per second. No material change in the velocities during storm flow has been made.

Disposal of the screenings and grit was effected by dumping, the screenings being covered by an appropriate depth of the relatively clean grit. All of the bearings on the screw conveyor grit washers were changed to sealed water wash bearings which improvement change has practically completely eliminated the large maintenance costs which formerly were attendant on this operation. After about 1.5 years of service, some of these bearings installed in one grit chamber as an experiment still show the original tool marks on the bearing.

During the year 1940 the manufacturer of the screenings centrifuge complied with the acceptance and guarantee tests on this unit.

Settling Tanks.—The settling tanks continued to function very satisfactorily during 1940. In spite of the fact that an effort was made to curtail the removals by the settling tanks until the South St. Paul-Newport plants were in operation, by reducing the retention period, the removals averaged considerably higher than the expected removal of 56 per cent of the suspended solids. With an average detention period during the year of only 1.5 hours, as compared with a possible detention period of somewhat over three hours at present flows, the average removal of suspended solids by the settling tanks was 71.1 per cent and of five-day biochemical oxygen demand 41.2 per cent. As an example of what could be accomplished by increasing the detention period, during most of the month of November, 1940, all of the settling tanks were placed in operation with an average detention period of 2.6 hours. Removal of suspended solids by the tanks during this month average 78.1 per cent, and of five-day B.O.D. 49.6 per cent. Sludge is pumped once each shift and a determined effort is made to secure as concentrated a sludge as possible. That such efforts were successful is shown by the fact that for the entire year solids concentration in the raw sludge pumped from the settling tanks average 80.7 per cent as compared with 77.9 per cent in 1939. As an aid in the direction of increasing sludge concentration, weighing of a definite volume of sludge pumped was inaugurated. At frequent intervals during the pumping period samples are drawn off and weighed by the operators of the sludge pumps, pumping being discontinued when weights fall below certain established minimums.

The skimmings removed from the settling tanks are ejected to an area south of the plant where they are covered with incinerator ash without nuisance.

In the 1939 Report mention was made of the difficulty due to breakage of links of drive chains on the sludge collection equipment, especially during the winter months. This was attributed by manufacturers to corrosive embrittlement. After a series of experiments with different type chains made of different materials, without satisfactory results, adjustable chain tighteners were placed first on one tank and then, after results were demonstrated, on all the settling tank drive chains. This simple expedient has eliminated all difficulty from this source.

During the year 1940 corrective efforts to eliminate wear on the shoes of the collector flights of the settling tanks were made. Prices were secured on new wearing shoes from the various manufacturers of this type of equipment, and from local shops. Because of the relatively high cost of replacement it was felt desirable to experiment with various schemes for welding wear-resistant material on the partially worn shoes rather than wait one or two years and completely replace all of the shoes. As a result of this experimenting, all the shoes on the settling tank equipment were stellited with two narrow beads on the worn portion of the shoe. This was done with the shoes in place on the flights at a fraction of the cost of replacement. After almost a year of service very little wear is noticeable.

The wear of the shoes already mentioned and evidences of wear on the sprockets and chains caused further experimentation in an endeavor to eliminate the continuous operation of the flights, which, because of the long tanks, was previously found to be necessary. Earlier efforts at part-time operation resulted in shearing pins on the drives and stalling the mechanism. With careful control, however, it was found shortly after the close of 1940 to be possible to operate the flights for a period of only two hours before and during each pumping. This has reduced the operating period to approximately one-third of its former value, which should cause a proportionate decrease in the amount of wear.

Effluent Filters.—At the close of the year 1940 the District had not as yet accepted the effluent filters from the manufacturer. As mentioned in previous reports, the major difficulty experienced by the manufacturer related to erosion and displacement of sand on the bed. After experimenting with various types of scrapers and levelers and after improving the side seals on the carriages, the manufacturer was able to secure satisfactory operation. Operation was considered sufficiently satisfactory to permit the manufacturer to begin guarantee tests in July of 1940. These were completed in April, 1941. The filters were operated during only a small percentage of the time in 1940, and therefore the increase in average removal accomplished by the filters during the year was somewhat small. Increased removal of suspended solids of 1.9 per cent and in B.O.D. of 1.4 per cent was accomplished by this short time operation.

A total of 8,897 millions gallons or 23.4 per cent of the total sewage flow was filtered during the year. There were 105 days of 24-hour operation and 73 fractional days of operation, usually but one of the two batteries of filters being in service at a time. The average suspended solids data for the 24-hour runs only, during which time the settling tank detention period was 1.6 hours and the filtration rate was 2.7 gallons per square foot per minute, are as follows:

Raw Sewage	295 p.p.m.
Filter Influent	76 p.p.m.
Filter Effluent	54 p.p.m.
Removed by Filters	22 p.p.m.

In regard to B.O.D. removals accomplished by the filters, the average 5-day B.O.D. of the filter influent during 1940 was 122 p.p.m., the effluent was 105 p.p.m., resulting in a removal of 17 p.p.m.

The effluent filters have passed the final acceptance tests but are still under a maintenance bond.

Vacuum Filtration.—Sludge from the settling tanks is pumped to concentration tanks where it is held for a short time to a usual maximum of three days for concentration. The tanks were effective from this standpoint, increasing the solids concentration from 8.07 per cent to 9.34 per cent as an average for the year. In addition, the tanks serve as a storage means and level off variations in solids content because of changing sludge characteristics. A total of 98.78 million gallons of concentrated sludge was filtered during the year. The average moisture content of the filter cake was 64.8 per cent and its average volatile content was 59.8 per cent.

Continued reduction in the quantity of conditioning chemicals was effected. During the year 1940 the quantity of ferric chloride was 1.92 per cent of the weight of the dry sewage solids, and the quantity of lime expressed on a calcium oxide basis was 4.76 per cent. Comparable figures for the year 1939 were 2.1 per cent and 5.68 per cent, respectively, and during 1938 were 3.17 per cent and 10.3 per cent, respectively. This reduction has been accomplished by careful and frequent checking and adjustment of the quantities of chemicals and by improvement changes in the conditioning tanks. The average life of filter cloth has been increased to 326 hours during 1940, which compares with 170 hours in 1939, and 160 hours during 1938. An average of 308.3 tons of filter cake was produced daily, containing an average of 108.4 tons of dry solids. The total quantity of filter cake produced during 1940 was 112,854 tons. The quantity of sludge produced was considerably higher than anticipated at the time of design, at which time it was expected that 76.5 tons of dry sewage solids would be produced daily. The increased quantity is due to higher sewage strength and greater removal by the plant than originally expected.

Incinerators.—During the year 1940 a total of 110,098 tons of filter cake containing 38,709 tons of dry solids was incinerated, in connection with which there was required a total of 663,500 kilowatt hours of electricity, amounting to 17 kilowatt hours per dry ton, and a total of 96,900 gallons of fuel oil, amounting to 2.5 gallons per dry ton. The fuel oil required was needed almost entirely in starting furnaces and taking them out of operation, as well as in holding temperatures in periods when operation was not required. A total of 15,565 tons of dry ash was produced, averaging 42.5 tons daily. The average tonnage of dry solids handled by each incinerator daily for the year was 52.8 tons. The average tonnage of combustible solids per incinerator per day was 31.6 tons.

Because of the inability to increase stack height due to the proximity to the St. Paul Airport, various alternate means of effecting economies were considered during the year. Shortly after the close of the year 1940, the preheater was removed from one incinerator as a means of reducing power and maintenance costs, as well as simplifying operations. To date, this unit has been in operation for about two months. Even this short time operation indicates that power costs can be reduced to one-third of their former values. This unit will be operated during the summer period so that by fall, the necessary improvement changes can be made in the other two furnaces.

Centrifuge Acceptance Tests

During the design of the treatment plant various methods of sludge disposal were considered, and after careful study, mechanical dewatering plus incineration was selected as the most satisfactory methods of sludge disposal for this plant. The two methods of mechanical dewatering that were considered were vacuum filtration and centrifuging. Vacuum filtration was chosen as the most satisfactory and economical. However, centrifuging appeared to offer some possibilities, particularly for dewatering ground screenings, and one forty-four inch unit was purchased from the American Centrifugal Corporation.

This machine had difficulty in handling the ground screenings alone. As produced at this plant the screenings contain an unusually high percentage of rags and other stringy material which the cutters had great difficulty in removing from the centrifuge bowl. However, when some sludge was centrifuged along with the ground screenings, the machine was able to function satisfactorily. It also performed satisfactorily on screenings containing a higher percentage of organic material and fewer rags.

Acceptance of the centrifuge was based on a series of twenty-one test runs on a screenings-sludge mixture. The centrifuge cake produced by the machine averaged 35.2 per cent solids and the liquid effluent averaged 1.1 per cent solids. The ratio of the screenings solids to the total solids in the screenings-sludge mixture fed to the centrifuge was 55.5 per cent. The mixture was fed to the machine at an average rate of 15,280 pounds of dry solids per 24 hours, compared with a specification requirement of 8,200 pounds dry screenings solids as a maximum. The specifications required that the cake produced should not contain more than 70 per cent moisture. The average of the 21 tests was 64.8 per cent moisture. Only one of the runs produced a cake with more than 70 per cent moisture and one run was as low as 47.6 per cent. The machine also complied with the vibration requirements of the specifications.

These tests indicate that the centrifuge has sufficient capacity to dewater the entire daily production of screenings, which averaged about 900 dry pounds daily in 1939 and 700 pounds in 1940. The maximum production for any single day was approximately 7,100 pounds in 1939 and 6,300 pounds in 1940, compared with a centrifuge capacity as indicated by the acceptance tests of 8,400 pounds per day. To date, however, disposal of the screenings has been regularly accomplished by hauling to the dump on plant property and covering with grit or ash. This method is the most economical at the present time and is quite satisfactory, particularly since the quantity of screenings is unusually low and the quantity of grit unusually high. In 1940 the removal of screenings and grit average 1.06 and 6.2 cubic feet per million gallons, respectively, compared with the averages of 3.1 and 4.0 for 117 other plants studied.

Studies of Sludge Filtration Problems

Some Buchner filtration tests were made in the laboratory to compare ferric chloride as a sludge conditioner with two other commercial coagulants both essentially ferric sulfate. The two ferric sulfate coagulants were about equal in effectiveness, but ferric chloride was much superior to both of them, giving 30 per cent to 50 per cent higher filtration rates at dosages equivalent on the basis of Fe content. Taking into consideration present delivered prices for the chemicals, these experiments indicated that the use of the ferric sulfate coagulants would cost 60 per cent to 70 per cent more than ferric chloride.

Some laboratory studies were carried out on lime slaking in an effort to determine the completeness of slaking, and whether it would be advantageous to preheat the slaker feed water. The lime used for sludge conditioning at this plant is a quicklime in pebble form, not over 0.75 inch in size, and has ranged from 91 per cent to 95 per cent available CaO as delivered, according to A. S. T. M. procedure C25–29. It would be rated as a fast slaking lime, according to A. S. T. M. test C5–26. As near as could be determined the addition of hot or cold water to the slaker made very little difference in the completeness of the slaking from a chemical viewpoint, the slaking being substantially complete in both cases. However, the physical condition of the hot water slaked lime, from the standpoint of smoothness, homogeneity and speed of filtration was much superior to the cold water slaked lime. The milk of lime from the hot water slaking tests filtered through a Buchner filter in about half the time required for the cold water slaked lime. This is a factor in favor of preheating the slaker water in plant operation, in respect to ease of filtration on the vacuum filters and minimizing of filter cloth blinding. In these laboratory tests the cold water supplied to the insulated slaking jar was at a temperature of 50° F., while that used for the hot water tests was added at 126° F. The water was added at the rate of 0.5 gallon per pound of lime, with continuous stirring. In the plant this milk of lime is further diluted as it leaves the slaker. In the laboratory experiments a maximum slaking temperature of 144° F. was observed in the cold water tests and 203° F. in the hot water tests.

The average life of filter cloths during 1940 was 326 hours, compared with 170 hours during 1939. This improvement in cloth life was probably due largely to the reduction in the amount of lime used as a sludge conditioning chemical and the resulting reduction in the amount of cloth blinding lime carbonate. The lime dosage was reduced from a 1939 average of 5.68 pounds of CaO per 100 pounds of sludge solids to an average of 4.76 pounds in 1940. This was accomplished largely through improvements in the distribution and mixing of the chemicals with the sludge. The effect of this reduction in lime dosage in minimizing the blinding of filter cloths is illustrated by the following data:

	Average for Cloths Examined In 1939	In 1940
Conditioning Chemical Dosage:		
% CaO	6.7	4.7
% $FeCl_3$	2.2	2.2
Service Life of Cloths, Hours	114	337
Analysis of Blinding Material in Cloths:		
% Lime as calcium carbonate	89.5	68.4
% Grease	5.3	24.3
% Iron as $Fe(OH)_3$	2.2	2.5
% Sand (acid insoluble material)	3.0	4.8

The percentage of lime in the blinding material has been considerably reduced although it still remains the predominant factor. With this reduction in lime, the importance of grease as a blinding material has increased a corresponding amount and becomes a significant factor.

Application of Incinerator Ash to Sewage Helpful

The possibility that the return of a portion of the incinerator ash to the incoming sewage might be of some benefit to the treatment processes has been considered at this plant. It was tried for the first time during the last part of September, 1940, when the sludge began to go septic and proved very difficult to filter, requiring considerably more conditioning chemicals than usual. Although no exact measurements were made, it was estimated that the addition of the ash amounted to between 5 and 10 per cent of the incoming sewage solids just ahead of the screen and grit chambers. The sludge filtration troubles began to clear up soon after and this part of the plant process was back to normal in a few days. The lime content of the ash probably assisted in restoring the sludge to normal. Increased removals in the settling tanks were also indicated, although the data were too meagre and conditions not stabilized sufficiently to permit a definite evaluation of the increase, if any.

Ash was again added during the first part of November. An average removal by the settling tanks of 80.8 per cent was obtained during six days of ash return, compared with 76.3 per cent for twelve days under similar conditions but with no ash return. However, more data will be needed before any definite conclusions as to the effectiveness of this process on sedimentation can be reached.

A few laboratory experiments indicated very little additional removals accomplished by the addition of ash. All of these trials were of a preliminary nature, however, and it is contemplated that more extensive work will be done in the future.

Summary of Operation Data

Item	1940 Average	
Sewage flow—average daily	104.2	m.g.d.
Screenings removal—per m.g. treated	1.06	cu. ft.
Wet weight per cubic foot	34.0	pounds
Moisture content	81.7	per cent
Volatile content	83.8	per cent
Grit removal—per m.g. treated	6.2	cu. ft.
Wet weight per cubic foot	86.9	pounds
Moisture content	15.1	per cent
Volatile content	11.9	per cent
Detention period—primary sedimentation	1.5	hours
5-Day B.O.D.:		
Raw sewage	210	p.p.m.
Settled sewage	120	p.p.m.
Removal—primary treatment	41.2	per cent
Suspended solids:		
Raw sewage	300	p.p.m.
Settled sewage	82	p.p.m.
Removal—primary treatment	71.1	per cent
Raw sludge—quantity	317,000	g.p.d.
Dry solids daily	110.2	tons
pH	5.9	
Solids content	8.07	per cent
Volatile solids content	64.8	per cent
Specific gravity	1.032	
Concentrated sludge—quantity	255,300	g.p.d.
Dry solids daily	103.2	tons
pH	5.8	
Solids content	9.34	per cent
Volatile solids content	62.4	per cent
Specific gravity	1.039	
Decanted liquor—quantity	74,800	g.p.d.
Solids content	0.675	per cent
Volatile solids content	63.2	per cent
Sludge filtration—daily rate, dry solids basis	4.29	lb. per sq. ft.
Conditioning tanks detention period	10	minutes
Lime applied (as CaO)*	4.76	per cent
Ferric chloride applied (as $FeCl_3$)*	1.92	per cent
Filter cake—quantity (wet)	308.3	tons daily
Solids content	35.2	per cent
Volatile solids content	59.8	per cent
Filtrate—quantity	209,000	g.p.d.
Solids content	0.515	per cent
Volatile solids content	39.0	per cent
Incineration—quantity (dry)	105.8	tons per day
Combustibles	63.2	tons per day
Water evaporated from filter cake	195.1	tons per day
Water added for temperature control	75.4	tons per day
Total water evaporated (per ton combustibles)	4.3	tons
Power consumption (per ton dry solids)	17	kw. hrs.
Oil consumption (per ton dry solids)	2.5	gallons
Operation and maintenance cost (per m.g.)	$8.05	

* Lbs. per 100 lbs. sludge solids, not cake solids.

THE GADGET DEPARTMENT.

The three devices presented here were the prize winners in the Gadget Contest which was part of the meeting of the New York State Sewage Works Association, at Niagara Falls, New York, in June, 1941.

First Prize

Liquid Depth Sampler

By J. A. Fitzgerald

Sewage Works Superintendent, Hudson Falls, N. Y.

In the absence of a satisfactory digested sludge sampler on the market, the "Jafitz" sampler was designed and has proven definitely superior to makeshift devices used heretofore. That the sampler gets right down into heavy solids accumulations was established in its first trial, which yielded a sample having a much higher percentage of fixed solids and less of volatile solids than samples procured previously. Factors

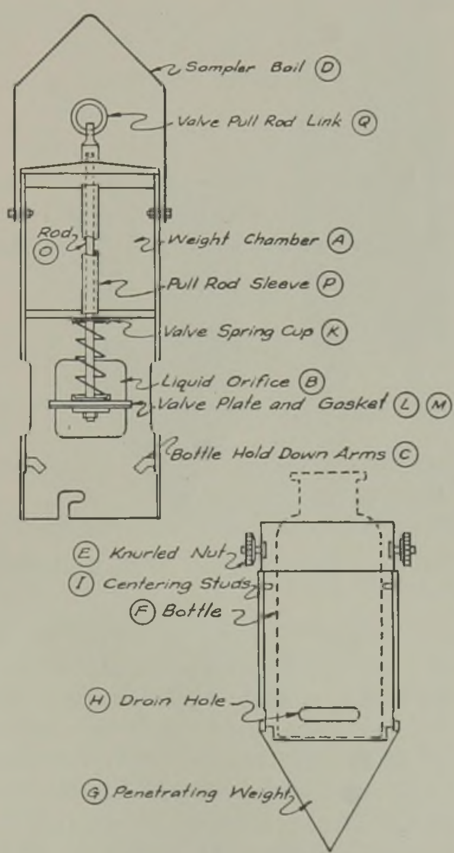

Fig. 1.—Jafitz liquid sampler. Designed by J. A. Fitzgerald, Hudson Falls, N. Y. (Pat. applied for.)

considered in the design were safety, ability to penetrate, operation under hydrostatic pressure and simplicity.

Safety is assured in making the sampler entirely of brass which eliminates any explosive hazard by sparks in the presence of gas.

Penetration is provided for by the pointed weight on the bottom section which permits easy entrance through scum and into heavy sludge at the bottom of digestion tanks. For ordinary use in digestion tanks, no other weight is required, since the total weight of the sampler is seven pounds.

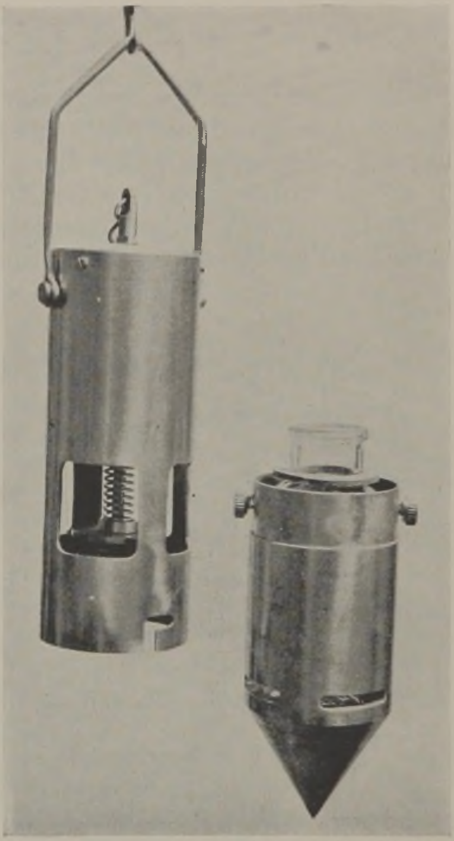

FIG. 2.—Jafitz liquid sampler. (Pat. applied for.)

Hydrostatic pressure has little or no effect on the sampler valve. The valve spring has a pull of six and one-quarter pounds and for ordinary use in digestion tanks, a very slight snappy pull opens the valve at desired depth. The sampler can be used for water or other liquids at greater depths and has been tested at sixty-five feet in Lake George. All that is required is a little snappier pull on the valve chain as depth is increased and once the valve is opened, it remains open until released. However, when the sampler is used at depths of fifty feet or more, approximately six pounds additional weight is added into the extra weight chamber in the top of the upper section. Lead shot can be used for this purpose.

The sampler is cylindrical in type as shown in Figs. 1 and 2, and is made in two sections, the upper containing valve, valve mechanism, extra weight chamber "A," liquid orifices "B," sample bottle hold down arms "C," and bail or handle to which is attached the lowering chain "D."

The lower section inserts into the upper section and is secured with two round knurled nuts "E." This section contains sample bottle "F," pointed weight at bottom "G," drain holes "H" and bottle centering studs "I." The valve and valve mechanism as shown in the drawing consists of valve spring "J," valve spring cups "K," valve plate "L," valve plate gasket "M," valve gasket and guide to bottle neck "N," the valve pull rod "P," and valve pull rod link "Q," to which is attached the valve opening chain with depth markers at one foot intervals. In taking a sample, the sampler is lowered to the desired depth with the lowering chain with the valve chain slack. A slight snappy pull on the valve chain opens and holds the valve open until released. Liquid enters through the orifices in the upper section.

Cleaning is easily accomplished by dousing in a pail of water or by hosing without any danger of water entering into the sample. Drain holes in the bottom section permit thorough circulation of water for this purpose.

If the sampler is to be used for water or other thin liquids where there is no presence of gas, it can be made of less expensive material than brass and a flat weight can be installed in the bottom section instead of the pointed one necessary to penetrate sludge.

Second Prize

Sludge Grinder

By E. A. Marshall and E. A. Larson

Sewage Treatment Works, Geneva, N. Y.

This grinder, illustrated in Figs. 3 and 4, was made from a Model "A" Ford car and an apple cider grinder. The apple grinder was mounted on the rear of the chassis after the back wheels, body and drive shaft were removed, the frame was cut and "V'd" together, and part of the drive shaft was bolted through the V to act as a towing and tie pole to haul it from place to place. One half of the differential housing is used for a standard when the grinder is in operation.

The engine mounting and transmission was not disturbed; part of the drive shaft was machined and a 3 belt, V-type pulley was keyed to the shaft. The driven end of this shaft is attached to the transmission through the universal joint, and the other end is fastened to the frame by a pillow block bearing.

The grinder mounted on the rear of the chassis consists of a drum 12 inches in diameter, 12 inches wide, and has 10 grinder blades spaced equally around the circumference which fit in ¼ inch by ¾ inch grooves and held in place by a collar or rim that slips over both ends of the blades and around the drum. The blades are adjusted by means of set screws; one located just above the blade in the rim, and another just below the blade in the drum.

FIG. 3.—Rear view of sludge grinder, built by E. A. Marshall and E. A. Larson, Geneva, N. Y.

The grinder blades are made from cold rolled steel. Teeth are machined into the blades spaced 5⁄16 of an inch apart and ¾ of an inch deep and the grinding side and tip of the teeth are then stellited, to make them wear longer. The drum of the grinder is keyed to a 1½ inch steel shaft and mounted on bearings bolted to a square maple frame, which is mounted on the rear of the chassis. The grinder is driven by a 4 inch, V-type, 3 belt pulley, which is keyed to the grinder shaft directly above the 1½ inch V-type, 3 belt pulley connected to the Ford engine. The speed of the grinder is controlled through the transmission and the engine is set at a certain speed so not to overheat.

The grinder is enclosed by a box built around it with a hopper on top and cast iron concaves on the grinding side, which concaves are adjustable. The size of the ground material is controlled by the speed of the grinder.

This machine will grind approximately 4 cubic yards an hour, to the size of rice or finer.

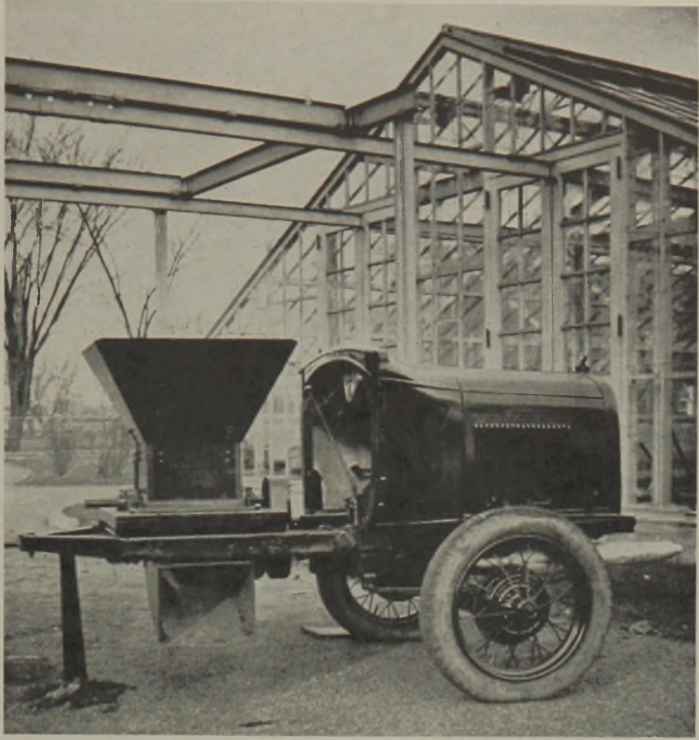

FIG. 4.—Side view of sludge grinder, built by E. A. Marshall and E. A. Larson, Geneva, N. Y.

Cost of the grinder, exclusive of builder's labor, was $76.67, which is itemized as follows:

Ford	$20.00
Grinder	10.00
Welding and Material Cost	46.67
	$76.67

THIRD PRIZE

Lawn Sprinkler

BY BRUCE STRONG

Sewage Treatment Works, Olean, N. Y.

An old automobile brake drum, a few pipe fittings, a small amount of welding and five ordinary garden hose nozzles (costing about 25 cents each) yielded this efficient and economical lawn sprinkler. Assembly details and the finished product in operation are shown in Figs. 5 and 6, respectively.

The sprinkler may be conveniently moved about while in operation because of the rounded bottom. Other advantages are: low cost, a large maximum area of coverage and adjustability of coverage. That the gadget is simple and easy to construct will be evident from Fig. 5.

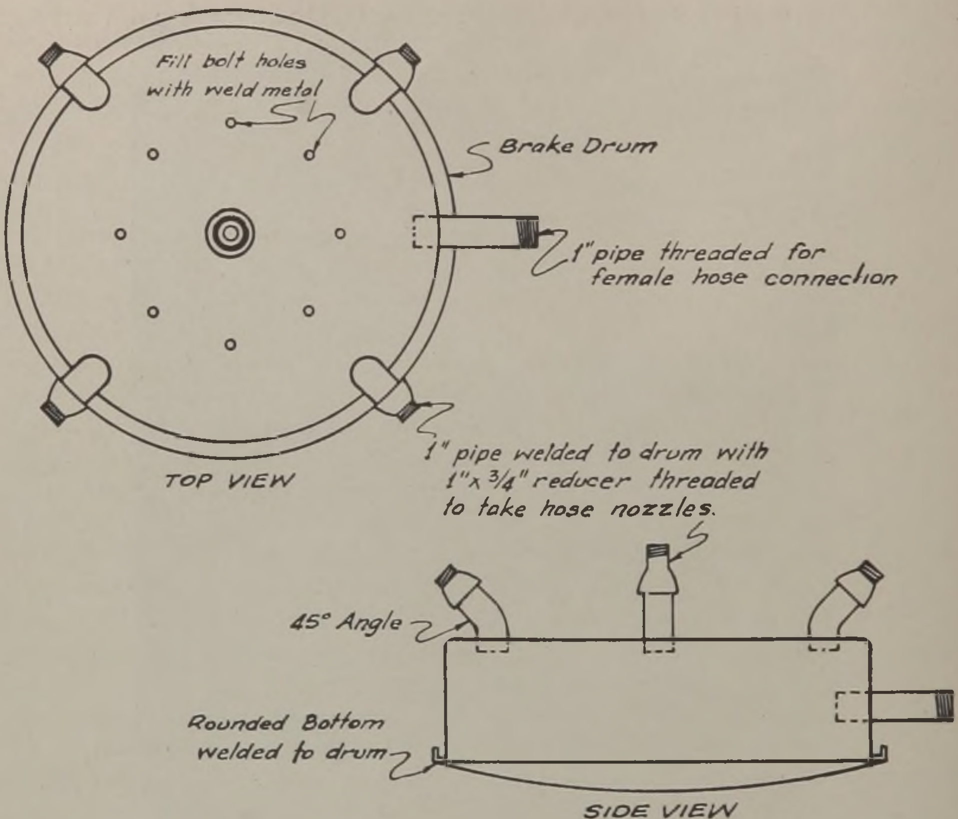

FIG. 5.—Portable lawn sprinkler made from brake drum. Submitted by Bruce Strong, Olean, N. Y.

FIG. 6.—Portable lawn sprinkler in operation. Made by Bruce Strong, Olean, N. Y.

NORTH DAKOTA OPERATORS DISCUSS PROBLEMS*

Reported by

K. C. Lauster

Associate Sanitary Engineer, State Department of Health

The session was opened by a discussion on the subject of Protective Coverings for Metal and Concrete in Sewage Treatment Plants by F. W. Pinney, Superintendent, Fargo sewage treatment plant. Mr. Pinney's experiences at the Fargo plant with several types of coatings were related. Costs for various methods of cleaning broken down into labor and materials were given, as were costs of coating applications with the same breakdown. Cleaning metal work with sanding machines gave good results, Mr. Pinney stated. Sand-blast cleaning was estimated to vary from 4 to 7 cents per square foot. Flame or torch cleaning was estimated at from 7 to 10 cents per square foot. The cost of oxygen and acetylene gas accounts for this high cost. Cleaning at the Fargo plant with sanding machines figuring labor at 50 cents an hour was 3 cents per square foot. About 2.3 cents was for labor and 0.7 cents was for equipment. Labor and equipment costs in painting, applying four coats as recommended by the manufacturer, was about 2.1 cents per square foot for labor and around 5.4 cents per square foot for material, or a total of 7.5 cents.

Mr. Pinney feels that protective coatings to obtain the best results should be selected experimentally because conditions in different plants vary to the extent that a coating successfully used in one plant may not meet the purpose at all in another. Of extreme importance is the care taken in the cleaning of the surface and the proper application of the coatings.

A variance of opinion was observed regarding efficacy of various methods of cleaning, some preferring sand blasting, others wire brushing, and still others the sanding method. The point was brought up as to whether or not replacement of metal works in certain instances may not be cheaper than attempting to keep corrosion under control. One of the biggest problems is to maintain structural steel work in trickling filter housings. More information on these problems will be looked for after another year's experience.

W. W. Tholstrup of the Wallace & Tiernan Company presented a very interesting and discussion-promoting talk on the subject of Chlorination in Sewage Treatment. He traced the history of chlorine uses, citing the earliest use as being in odor control with the objection that chlorine at that time was high in cost and containers for handling were quite a problem. Present-day uses include control of ponding which is usually a condition brought about by slime accumulation which in turn may entrap inert material. Twenty-five parts per million chlorine in

* Notes from operation forum included in Thirteenth Annual Meeting of the North Dakota Water and Sewage Works Conference, Jamestown, North Dakota, October 14, 1941.

sewage dosed on the filter at various intervals has been a successful method of control. For odor control it was suggested that chlorination in the collection system is usually best. The point of application, of course, is important to prevent hydrogen sulfide from forming. Mr. Tholstrup stated their company was reluctant to accept theories that chlorination was of value in the control of filter flies and foaming of Imhoff tanks, but that chlorine applications had been used for such purposes and such use has been advocated. For grease removal, chlorine injected either into the sewage or into the air used for aeration may increase grease removal from 50 to 80 per cent. Chlorination of sewage prior to aeration is preferred principally due to corrosion difficulties in equipment when chlorine is injected with the air. B.O.D. removals by chlorination usually average 17 to 20 per cent and may be as high as 30 per cent. Break-point chlorination may give 50 to 60 or even 70 per cent B.O.D. reduction.

A lively discussion followed in which the point was brought up by Mr. DeWitte Nelson, chemist, Armour & Company treatment plant, West Fargo, as to whether or not the ultimate B.O.D. is appreciably affected by chlorination as normally practiced, it being felt that possibly the chlorine acted more as an inhibitor which reduced the 5-day B.O.D. but that actual oxidation may not be accomplished and thus the ultimate B.O.D. remain practically unaffected. The point was brought up that in some cases chlorination merely served to inhibit the B.O.D. whereby the pollutional effects were carried farther downstream and thus involved more suitors in court cases. The conclusion reached was that chlorination definitely has its place in sewage treatment and is applicable in certain instances. Chlorination of clarified sewage effluent is of value for disinfection. The inhibition of B.O.D. is much more likely to be beneficial than injurious. The case cited where chlorination was injurious was probably due to the fact that the sewage had a very high B.O.D., was treated only by sedimentation, and the dosages employed were insufficient. Standard oxidation processes are more economical down to a certain B.O.D. reduction as is evidenced by standard practice.

Mr. Tschida, superintendent, sewage treatment plant, Dickinson, in a discussion of the operation of digesters, brought out several operating difficulties which he was experiencing. Solution of the problems was difficult to reach on the basis of operating procedures at other plants because of the inherent differences in the design of various plants. However, it was interesting to hear the operating difficulties and solutions at Mr. Tschida's plant as well as others. Certain points remained unsolved which will be pursued in the future.

A brief discussion pointing out some of the records that should be kept by sewage treatment plant operators and the value of such records was given by K. C. Lauster, associate sanitary engineer, State Department of Health. Records may become of inestimable value in indicating clearly just what the plant is doing and where savings might be effected, are valuable protection against complaints, useful in lawsuits and in determining the necessity of plant enlargement. Detailed records frequently offer solutions to individual operating problems and are invaluable for budget preparation.

In the discussion on the operation and maintenance of lift stations, Mr. Kleven, superintendent, pointed out the benefits derived in the Grand Forks system by setting the lift pumps to operate at frequent intervals, thus considerably reducing the septicity of the sewage reaching the plant. He also mentioned that the rise in pumping costs at one lift served as a clue to an investigation which revealed the intake to be partially plugged with boards which were left by careless workmen. Mr. Pederson, operator, pointed out that the ventilation problems at the Valley City lift station were automatically taken care of by boys with slingshots and air rifles. He was unable to keep windows in the lift station and the resulting ventilation made it much easier to open the doors in winter weather!

James Stewart, chemist, reviewed some of the experiences on the trickling filters at the Fargo sewage treatment plant which were published in the September issue of *Official Bulletin.* He re-emphasized the difficulty in obtaining representative samples from trickling filter effluent because of extreme variation in B.O.D. of the effluent observed between the beginning and the end of the dosing cycle.

The discussion on the operation of unhoused trickling filters was very interesting, especially in view of the fact that some cities are investigating the results obtainable with unhoused filters in North Dakota. At Grafton and Wahpeton where only half of the filters are housed, no attempts have been made to operate the unhoused portions during cold winter temperatures and relative efficiencies of the housed and unhoused portions have not been checked as the weather becomes progressively colder until the unhoused portions are thrown out of service for the winter. Jamestown reports good efficiencies with all windows open in the filter housing during winter weather, although operating results are meager. Minot confirmed this. Fargo, Wahpeton, and Grafton report considerable ice formation in housed trickling filters unless windows are closed or almost closed. The general conclusion reached was that construction of unhoused filters for North Dakota should be undertaken only with extreme caution and such construction was discouraged. The apparent difference in ice formation at various points may be explained by the relative proportion of natural shelter at the various treatment plants. Considerable ice difficulty was observed at the Armour plant at West Fargo in spite of the high temperature sewage (about 100 degrees) and the high, uniform flow. Mr. Colsen, operator at Grafton, pointed out that possibly a lesson from the sheep herders could be learned. The sheep raisers claim a shelter with walls 14 or more feet in height without a roof is better than a completely housed shelter with window ventilation because of reduced drafts. He might have something there.

Little trouble has been experienced with the presence of filter flies and in none of the plants has ponding become serious. Wahpeton reported some filter fly trouble and is contemplating seeding their filter with achorutes viaticus, or the well-known springtailed "skippers," from the Fargo plant.

TIPS AND QUIPS

Superintendent J. C. MacDonald, of Brazil, Indiana, reports an interesting experience in dewatering poorly digested sludge on drying beds.

To relieve foaming Imhoff tanks, a 14-inch depth of thin sludge was pumped to one of the drying beds on April 10, 1941. Drainage was far from normal, there being a 4-inch depth of water at the surface and profuse gasification of the sludge in the bed, which condition persisted until June 17 (68 days). In an effort to speed dewatering, the water at the surface was pumped off and MacDonald noted that the remaining muck appeared to be driest at the bottom, causing him to conclude that the sand surface was sealed. Donning his boots, he waded back and forth through the bed, lengthwise and crosswise, thoroughly churning the contents.

Three days later, it was possible to remove several loads of fairly dry sludge and seven days later, the bed was clean and raked, ready for service.

* * * * *

Although represented at the Second Annual Convention of the Federation by 49 members as compared to 185 members of the New York State Sewage Works Association, the Central States Association was found the attendance leader on the basis of man-miles travelled. Computations made by A. W. Eustance of the Registration Committee revealed that attendance by Central States members involved 38,600 man-miles of travel, against 28,600 man-miles by New York members. Other Member Associations which were well represented were New England (35 members), New Jersey (29 members) and Pennsylvania (25 members).

Quarter-matching contests at the Saturday Luncheon and the Board of Control dinner yielded sufficient revenue to purchase a trophy to be awarded each year to the Member Association making the best attendance showing. The trophy will be awarded to the Central States Association at its June, 1942, meeting, to be retained until the Cleveland Convention.

* * * * *

Unusual results in grease removal from a sewage containing a large volume of packinghouse waste were reported by Leland Bradney, Chemist at Sioux Falls, Iowa, while addressing the South Dakota Water and

Sewage Conference at Aberdeen. Operation with aero-flocculation and sedimentation gave a removal of 50 to 55 per cent, which was increased to 75 per cent by return of waste activated sludge to the raw sewage before aero-flocculation. Conversion of the old, square, cross-flow settling tanks to the center-feed, peripheral-flow units further increased total grease removal to 90 per cent.

* * * * *

Imagine the consternation of the Sheboygan, Wisconsin, owner of Duke, a year-old springer spaniel, when the dog suddenly disappeared below the surface of Lake Michigan while romping at the water's edge. Investigation revealed that the pup had been drawn into a submerged intercepting sewer manhole, the cover on which had been broken.

Racing to the sewage treatment plant, the dog's master recited his story to Superintendent Jake Klein, who immediately dispatched two men to the screen room to watch for the dog while two others went to an emergency pumping station on the sewer above the plant. When a manhole cover at the latter point was raised, there was Duke—weak, bedraggled and whimpering as he clung to the iron ladder. The rescue was quickly effected and Duke was restored to his owner, little the worse for his half-mile, 30-minute tour of the intercepter.

Klein's prompt action in accomplishing this humane deed was commended highly in local newspapers. Thus the plant and himself was accorded desirable public recognition as well as the lasting gratitude of Sheboygan's dog lovers.

* * * * *

In the experience of the "Corner," it is unusual to find an institutional sewage treatment plant setting the pace for municipal works. The ice has been broken by Superintendent Thomas M. Gwin, whose Folsom Prison plant was voted the 1941 Award of Merit by the Committee on Awards of the California Sewage Works Association. Mr. Gwin may be justly proud of this recognition.

* * * * *

Sewage works operation in New York State is reaching such a level of excellence that the Rating Committee of the New York State Sewage Works Association is finding it increasingly difficult to select the winner of the Annual Operator's Award. Judging of the 1940 annual reports submitted as entries resulted in a tie for first place and duplicate trophies representing the 1941 Award were presented to William D. Denise, Operator of the plant serving the Greece Sewer District and to James T. Lynch and H. E. Milliken who are jointly responsible for the operation of the plant at Auburn, New York.

The presentation was made at the meeting of the Association held at Niagara Falls, New York on June 19–21, 1941, by Charles C. Agar, Chairman of the Rating Committee.

OFFICE OF PRODUCTION MANAGEMENT

Division of Priorities

All chlorine produced in the United States will be subject to direct allocation after February 1, 1942, in accordance with the terms of an amendment to General Preference Order M–19 issued today by the Director of Priorities. War demands for chlorinated products have accentuated the shortage of chlorine which was the occasion for placing chlorine under full priorities control on July 28, 1941.

To facilitate allocation, a new type of requirement is now provided for scheduling orders for chlorine. Regardless of priority ratings, no producer of chlorine may accept orders after the 10th day of any month for delivery in the next calendar month without a specific direction from the Director of Priorities. No distributor of chlorine may accept orders after the 5th day of any month for delivery in the following month without specific direction from the Director of Priorities. All producers of chlorine are required to file with the Chemicals Branch of the Office of Production Management in Washington, on or before the 15th of each month, on Form PD–191, a schedule of deliveries to be made the following month.

After February 1, 1942, no deliveries of chlorine may be made without specific authorization from the Director of Priorities. Authorizations will be based on a review of the schedules submitted, in the light of defense and essential civilian requirements. If no change in the proposed schedule is made by the Director of Priorities by the 25th day of the month, deliveries in the following month may be made according to the schedule as submitted. All orders for chlorine must be accompanied by Form PD–190 properly executed.

Another provision of the amended chlorine order specifies priority ratings which are to be granted to orders for chlorine for certain purposes. This assignment of ratings appears in the copy of the order attached to this release.

Under the amended order, every producer of chlorine is required to set aside each month 5 per cent of his estimated monthly production of liquid chlorine. The producer is to make no commitments with respect to this chlorine reserve. However, subject to the general provisions of Priorities Regulation No. 1, the reserve chlorine may be sold and delivered if no express order for its disposition has been issued by the Director of Priorities by the 15th day of the month in which the reserve is set aside. Non-defense as well as defense orders for chlorine must be accepted by producers if a priority rating has been assigned to such orders.

Except for the allocation provisions which become effective February 1, 1942, today's amendments to General Preference Order M–19 go into effect immediately and will remain in effect until revoked by the Director of Priorities.

TITLE 32—NATIONAL DEFENSE

CHAPTER IX—OFFICE OF PRODUCTION MANAGEMENT

SUBCHAPTER B—PRIORITIES DIVISION

Part 960—CHLORINE

AMENDMENT NO. 1 TO GENERAL PREFERENCE ORDER NO. M-19

To Conserve the Supply and Direct the Distribution of Chlorine

(*a*) Section 960.1 (General Preference Order No. M-19) is hereby amended to read as follows:

Whereas, the national defense requirements have created a shortage of Chlorine, as hereinafter defined, for defense, for private account, and for export, and it is necessary, in the public interest and to promote the defense of the United States, to conserve the supply and direct the distribution thereof;

Now, therefore, it is hereby ordered that:

960.1 General Preference Order (*a*) *Definitions.*—For the purposes of this Order:

(1) "Chlorine" means gaseous and liquid Chlorine.

(2) "Producer" means any person engaged in the production of Chlorine and includes any person who has Chlorine produced for him pursuant to toll agreement.

(3) "Distributor" means any person who purchases Chlorine for resale.

(*b*) *Applicability of Priorities Regulation No. 1.*—Control of the supply and direction of the distribution of Chlorine is hereby taken by the Director of Priorities, and all future transactions of any kind in Chlorine are regulated and governed by the provisions and definitions contained in Regulation No. 1 of the Priorities Division of the Office of Production Management, issued on the 27th day of August, 1941, except as herein otherwise specifically provided.

(*c*) *Placing Orders.*—Anything in Priorities Regulation No. 1 to the contrary, notwithstanding,

(1) No Producer shall, except as the Director of Priorities may otherwise direct, accept an order, whether it be that of a Distributor, another Producer, or a consumer, for delivery of Chlorine unless such order has been placed with him by the 10th day of the month preceding the month in which delivery is sought, and unless such order is accompanied by Form PD-190 (in duplicate) properly executed by the person placing such an order. The Form PD-190 submitted by a Distributor must be accompanied by the original and one copy of Form PD-190 submitted to him in accordance with the provisions of paragraph (*c*) (2) hereof in connection with orders accepted by him.

(2) No Distributor shall, except as the Director of Priorities may otherwise direct, accept an order for delivery of Chlorine unless such order has been placed with him by the 5th day of the month preceding the month in which delivery is sought and unless such order is accompanied by Form PD-190 (in triplicate) properly executed by the person placing such order.

(3) No producer or Distributor shall make, and no person shall accept, delivery of Chlorine unless and until Form PD-190 hereinabove referred to has been properly executed and timelily filed in accordance with the provisions of paragraphs (*c*) (1) and (2) hereof.

(*d*) *Withheld Deliveries.*—

(1) No Producer shall make commitments for the sale or delivery of liquid Chlorine during the month of February, 1942, or any calendar month thereafter, with respect to an amount of liquid Chlorine equal to five per cent (5%) of his estimated monthly production.

(2) No Producer shall deliver liquid Chlorine as to which commitments may not be made pursuant to paragraph (*d*) (1) hereof, except upon express instructions of the Director of Priorities. If by the 15th day of the month in which a Producer is required by the provisions of paragraph (*d*) (1) hereof to withhold deliveries of liquid Chlorine, the Director of Priorities has issued no instructions with respect to the disposition of such liquid Chlorine, Producers may make deliveries of such liquid Chlorine without regard to the restrictions contained in paragraph (*c*) hereof, but subject, however, to the provisions of Priorities Regulation No. 1.

(*e*) *Delivery Schedules.*—

(1) Form PD-191 (in triplicate) properly executed, which shall contain, among other things, a schedule of deliveries which such Producer proposes to make in the succeeding month, the preference rating, if any, applicable to each delivery, the orders tendered to him for delivery during the succeeding month which he has not scheduled, his estimated production for the succeeding month and the amount of liquid Chlorine to be reserved for the succeeding month in accordance with the provisions of paragraph (*e*) hereof, shall on or before the 15th day of each calendar month be filed by each Producer with the Chemicals Branch of the Office of Production Management, Washington, D. C. Such Form PD-191 shall be accompanied by the duplicate copies of every Form PD-190 submitted to the Producer. After such Form PD-191 has been filed with the Chemicals Branch of the Office of Production Management, any changes of circumstances or matters occurring thereafter affecting the accuracy of the statements contained in such Form PD-191 shall be forthwith reported to the Chemicals Branch of the Office of Production Management.

(2) On and after February 1, 1942, except as provided in paragraph (*d*) (2) hereof and except as may be otherwise specifically authorized by the Director of Priorities, no deliveries of Chlorine shall be made by a Producer to any person unless and until the same shall have been authorized by the Director of Priorities. Such authorization by the Director of Priorities shall be based primarily upon insuring the satisfaction of all defense requirements and providing an adequate supply for essential civilian uses. Each Producer shall, upon being apprised of the deliveries which have been authorized by the Director of Priorities, forthwith notify his customers of the extent of such authorization as the same may affect them. Each Distributor shall, upon being apprised by the Producer of the extent to which deliveries to such Distributor have been authorized by the Director of Priorities, forthwith notify his customers of the extent of such authorization as the same may affect them. If, however, by the 25th day of the month preceding the month in which deliveries are to be made, no instructions have been issued by the Director of Priorities, Producers may make deliveries of Chlorine in accordance with, and only in accordance with, the schedules filed by them with the Chemicals Branch of the Office of Production Management.

(*f*) *Assignment of Preference Ratings.*—

(1) Deliveries under all defense orders which have not been assigned a higher preference rating are hereby assigned a preference rating of A-10.

(2) Unless a higher preference rating has been specifically assigned by order of the Director of Priorities, and subject to Priorities Regulation No. 1, deliveries of Chlorine

for the uses (or for the manufacture of products for such uses) set forth below are hereby assigned the preference rating set opposite each such use as follows:

	Use	Preference Rating
(i)	Potable water treatment Sewage treatment	A-2
(ii)	Sanitation and sterilization in hospitals, clinics, sanitoria, diaper laundries, dairies and other food processing plants, public eating and drinking establishments, public and institutional swimming pools, surgical and medical supply manufacturing establishments Manufacture of products for medicinal, surgical, dental and veterinarian uses	A-6
(iii)	Food processing other than bleaching Food preservation	A-9
(iv)	Manufacture of vitamin products Manufacture of insecticides and fungicides Manufacture of catalyst materials Industrial water treatment Metals refining	A-10
(v)	Processing of pulps, as follows: (*a*) High alpha pulps (not less than 90 per cent Alpha Cellulose content) (*b*) Dissolving pulps (*c*) Nitrating pulps (*d*) Pulps used in the manufacture of photographic base papers (*e*) Pulps in which Chlorine is a processing rather than a bleaching chemical. Manufacture of petroleum product additives Manufacture of industrial chemicals and related products Manufacture of industrial plastics and rubber-like products	B-2
(vi)	Textile bleaching Pulp and paper bleaching not elsewhere classified Shellac bleaching Laundry bleaching	B-5
(vii)	Foodstuff bleaching Wiping rag and waste bleaching Cosmetics and toilet preparation	B-8

(*g*) *Acceptance of Certain Non-Defense Orders.*—When a non-defense order for Chlorine for a use specified in paragraph (*f*) (2) hereof to which a preference rating has been assigned, either by specific certificate or otherwise, is offered to a Producer or a Distributor, it shall, subject to the same terms and conditions applicable to the acceptance of defense orders set forth in Priorities Regulation No. 1, be accepted for scheduling on Form PD-191; and deliveries thereunder shall be scheduled in accordance with the preference rating assigned thereto and the delivery dates specified therein, even though deferment of deliveries under non-defense orders bearing a lower preference rating previously accepted is necessitated thereby, such deliveries thereunder scheduled to be subject, however, to revision by the Director of Priorities under the terms and conditions set forth in this Order. Deliveries shall then be made in accordance with the authorization of the Director of Priorities. Any person seeking to place a non-defense order to which a preference rating has been assigned must make application for acceptance of such order in the first instance to his regular Supplier (if a person has several regular Suppliers, the order should be divided among such Suppliers in accordance with each such person's normal method of placing orders).

(*h*) *Intra-Company Transactions.*—The prohibitions or restrictions contained in this Order with respect to acceptances of orders and deliveries in the absence of a contrary direction apply not only to acceptances of orders from and deliveries to other persons, including affiliates and subsidiaries, but also to acceptances of orders from and deliveries to one branch, division or section of a single enterprise by or from another branch, division or section of the same or any other enterprise owned or controlled by the same person.

(*i*) *Reports.*—Reports required by Priorities Regulation No. 1 hereinabove referred to shall be made as such times and on such forms as shall be prescribed therefor by the Chemicals Branch of the Office of Production Management.

(*j*) *Notification of Customers.*—Producers and Distributors shall, as soon as practicable, notify each of their regular customers of the requirements of this Order, but the failure to give such notice shall not excuse any person from the obligation of complying with the terms of this Order.

(*k*) *Violations or False Statements.*—Any person who violates this Order, or who wilfully falsifies any records which he is required to keep by the terms of this Order, or by the Director of Priorities, or otherwise wilfully furnishes false information to the Director of Priorities or to the Office of Production Management may be deprived of priorities assistance or may be prohibited by the Director of Priorities from obtaining further deliveries of materials subject to allocation. The Director of Priorities may also take any other action deemed appropriate, including the making of a recommendation for prosecution under Section 35(A) of the Criminal Code (18 U. S. C. 80).

(*l*) *Effective Date.*—This Order shall take effect immediately and shall continue in effect until revoked by the Director of Priorities.

(P. D. Reg. 1, Aug. 27, 1941, 6 F. R. 4489; O. P. M. Reg. 3 Amended, Sept. 2, 1941, 6 F. R. 4865; E. O. 8629, Jan. 7, 1941, 6 F. R. 191; E. O. 8875, Aug. 28, 1941, 6 F. R. 4483; sec. 2 (a), Public No. 781, 76th Congress, Third Session, as amended by Public No. 89, 77th Congress, First Session; sec. 9, Public No. 783, 76th Congress, Third Session.)

Issued this 20th day of December, 1941.

DONALD M. NELSON,
Director of Priorities

PHILOSOPHICAL SHORT STORY

Army, Navy,
Air Corps wary.
Driving Japs to
Hara kiri.

In World upset with
Strife and war,
Brighten "Corner"
Where you are!

EDITORIAL

ACTIVATED SLUDGE PRACTICE

This issue is almost a textbook on theory and practice of the activated sludge process. The comprehensive and informative report of Mr. Pearse and his Committee brings up to date practically all available information on activated sludge plant operation. The sections on diffuser plates, iron content, and operating data of representative plants contain information not available elsewhere, and quite helpful to operators of activated sludge plants.

One rather surprising conclusion appears, with reference to the relation of air consumption and B.O.D. removal, shown in Fig. 1. The plotted records for some nine plants show air consumption ranging from 500 cu. ft. per lb. of B.O.D. removed, when the removal is 100 p.p.m., up to 930 cu. ft. per lb. of B.O.D. removed, when the removal is 200 p.p.m.

This conclusion appears illogical, when compared with other biological relations. In trickling filters, chlorination, or chemical treatment, the unit removals are greater as the concentration of applied sewage increases. Trickling filters give increasing removals of B.O.D. per unit of stone, as the strength of sewage increases; chlorination and chemical treatment likewise evince increasing removals of B.O.D. per unit of chlorine or chemicals applied, with increasing strength of sewage treated. Whether the activated sludge phenomena are different, or the slope of the line may be different with more points, remains to be seen. It is likely that, in some plants, more air is used than the minimum required for the reduction of B.O.D. obtained, and such points may distort any generalization based on such a limited amount of data. The Report states that the line drawn between the points is only tentative. The writer is of the opinion that the slope of the line should be downward, rather than upward, if air is used efficiently.

The Report is the first compilation of activated sludge data to be published, with critical evaluation of the various control tests and operating variables. Several other papers, and recent books, have reported features of plant design, plus some operating data, but these papers and books have comprised hardly more than a catalogue of facts, and not a critical evaluation of the effects of variable factors on results obtained. In these papers and books, if innovations in design have been noted, it has been assumed that such innovations are improvements *per se,* or if some operators use unconventional tests, they are reported as improvements or advancements in activated sludge practice. This does not follow; many innovations may prove to be mere novelties, or personal preferences, rather than proven advances in activated sludge design and operation. The Pearse report attempts to define the most efficient, standard procedure for activated sludge plant control, and therefore it should be of real help to all operators who wish to compare their scheme of operation with that used at other activated sludge plants.

There are other valuable activated sludge papers in this issue. Mr. Gould describes the New York plants, particularly Wards Island and Tallmans Island, where the activated sludge characteristics are so different, and where step aeration is being studied experimentally to determine its advantages, if any.

Prof. Fair adds experimental data to the problems of step aeration and short circuiting. The experimental runs reported in Tables I and II, however, were based on such long aeration periods (three changes per 24 hours) that the data can hardly apply to the objectives sought in the design of Tallmans Island and the other New York plants (except Wards Island) where short periods of 2 hours or less were expected to result from the step-aeration design. Tallmans Island has had a flow of only 14 m.g.d., however, as compared with the design flow of 20 m.g.d., so a full-scale test of the results of step aeration has not been possible. Mr. Gould has, however, installed a testing station at Wards Island to investigate step aeration, and reports that results to date indicate an advantage when the aeration period is shortened to 1.5 hours.

Other activated sludge information in this issue includes:

A practical discussion on diffuser plates, and their cleaning, by Messrs. Schade and Wirts, of Cleveland; operating and construction costs of four activated sludge plants in Illinois, by Messrs. Babbitt and Farnsworth; a year's report on the Springfield plant, by Mr. Larson; maintenance procedure at the Chicago Southwest plant by Mr. Hageman; and comparison of conventional activated sludge operation with the Guggenheim Process, in experimental studies, by Messrs. Phelps and Bevan.

In fact, this issue ought to be dedicated to activated sludge plants and operators. The publisher is hereby authorized to break a bottle of the Lancaster, Pa., activated sludge effluents over the presses, when the JOURNAL goes to press.

F. W. MOHLMAN

Proceedings of Local Associations

OHIO CONFERENCE ON SEWAGE TREATMENT

Fifteenth Annual Conference, Mansfield, Ohio, September 18–19, 1941

The Fifteenth Annual Ohio Conference on Sewage Treatment was held at the Mansfield-Leland Hotel, Mansfield, Ohio, on September 18 and 19, 1941. The registered attendance was 125.

Heretofore, and including this meeting, the conference has been called by the State Department of Health but, due to changing circumstances, it was considered advisable to adopt a new constitution. The major changes resulted in direct affiliation with the Federation of Sewage Works Associations and the reorganization as an independent operators conference group. The same name was retained as was selected at the first annual meeting in 1927.

The new officers elected for the ensuing year were:

Chairman .... A. H. Niles, Toledo
Vice-Chairman .... R. F. Snyder, Massillon
Secretary-Treasurer .... W. D. Sheets, Columbus
Director .... F. W. Jones, Cleveland

The technical papers presented covered subjects of especial interest to both operating personnel, to the sanitary engineering profession and to those affiliated with certain industrial waste treatment processes as particularly related to canneries and the ferrous metal industries. They included the following:

"Development of Sewage Treatment in Ohio"—F. H. Waring, Columbus.
"Sanitation Problems in Connection with National Defense"—Major B. F. Hatch, Columbus.
"Mansfield Sewage Treatment Plant Operation and Design"—J. R. Turner, Mansfield.
"Cannery Waste Treatment"—N. H. Sanborn, Washington, D. C.
"Progress in the Treatment and Utilization of Metallurgical Plant Wastes"—W. W. Hodge, Pittsburgh.
"B.O.D. Dilution Water—Past, Present and Future"—R. D. Scott, Columbus.
"Design Problems to Meet Operating Conditions"—Floyd G. Browne, Marion.
"Diffuser Plate Cleaning vs. Compressed Air Costs"—J. J. Wirts, W. F. Schade, Cleveland.
"Bathing Beach Waters of Cleveland"—Paul Van Gieson, Cleveland.

The afternoon of the first day was devoted to split sessions and group discussions. The former consisted of separate meetings of a technical and a non-technical group where timely topics were discussed. The usual group discussions featured "Maintenance of Sewage Works," "Activated Sludge Treatment," "Sewage Filtration," "Sewage Sludge Treatment and Disposal," and "Laboratory Practice and Control." The following morning at the conference breakfast the group leaders summarized the respective discussions.

The annual conference dinner was well attended. The dinner speaker was W. J. Russell, manager of Appliance Engineering Department, Westinghouse Electric Company, Mansfield, Ohio. His timely subject was "Problems Relative to Substitution of Materials, Defense Requirements."

On publication, a copy of the 1941 Report of Ohio Conference on Sewage Treatment will be furnished each registrant. To make possible its publication, a nominal charge will be made for copies requested by persons not registered at this conference. Announcement will be made when the current report is ready for distribution.

Bruce M. McDill, *Secretary*

NORTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

Thirteenth Annual Meeting, Jamestown, North Dakota, October 13–15, 1941

The meeting was called to order at 10:30 A.M., October 13 by President R. M. Jenson. Mayor Perry Johnson welcomed the Conference to Jamestown. In his address, emphasis was placed on the need for greater recognition by city officials of the importance of competency in water and sewage works operators and the necessity of educating city officials in this regard. As a municipal official, he endorsed the Conference program for certification of operators.

President Jenson reviewed the progress of the Conference during the year and expressed his appreciation for the active cooperation of the membership and especially of the committees. The increase in the number of towns represented was pointed out as an indication of progress. Operators and officials from ten cities not represented at the previous meetings were present this year. President Jenson stressed the need for greater attention to the care and maintenance of existing water and sewage works, since replacement may be difficult in view of national defense activity. He urged operators to continuously prepare themselves for more competent operation and to participate in the voluntary certification program of the Conference. Each member was appointed a one-man membership committee to contact towns not represented in the Conference.

Operators and officials were cautioned to determine the exact status of their water and sewage works in order to detect weak spots and to plan necessary improvements and other needs far enough in advance to assure uninterrupted operation. A gain in membership and an increase in the treasury balance were cited. Challenging problems facing the

Conference reviewed in the president's closing remarks included: carrying out a successful certification program pointed toward a State licensing law; bringing the services of the Conference to more of the smaller communities; increasing the level of plant operation; strengthening the relationships between operators and local governing officials; and studying of operating problems by Conference committees.

Minutes of the last meeting were read by the secretary and approved as read.

Following presentation of the financial report which showed a net balance in the treasury of $257.04, the president announced that the auditing committee would be appointed later in the meeting to review the report.

New business opened with a motion by W. E. Gilbertson and seconded by Dan Krause that the president be allowed necessary minimum expenses to attend one out-of-state meeting during the year. Motion carried.

A discussion on the appointment of an advertising committee to inform prospective advertisers of the availability of space in the Official Bulletin followed. Steve Monek expressed the opinion that operators and operating officials could assume the responsibility for informing new prospective advertisers in this regard. No action was taken.

President Jenson asked Mr. Monek for a discussion of the work of the Publicity Committee. In response, Monek stated that the work had been confined mostly to newspaper releases. W. E. Gilbertson pointed out the opportunities for public relations activity through local radio stations and cited broadcasts from both water and sewage treatment plants in the state.

The president discussed the appointment of committees on constitutional changes with respect to conforming to the Federation of Sewage Works Associations' constitution and by-laws and with respect to elevation of the vice-president to president. Dean Chandler stated that the latter subject had been discussed by the Nominating Committee on a previous occasion and that he believed the matter could best be handled by precedent, if desirable, rather than by constitutional change.

A motion by W. Gilbertson and seconded by D. MacDonald, that the secretary be instructed to send telegraphic greetings and a convention badge to Honorary Life Member Bill Littlehales, ill in the hospital.

Appointment of the following committees was made by the president:

Auditing Committee: H. T. Hintgen, Wahpeton, *chairman;* Oscar Jordheim, Fargo; R. J. Lockner, Cooperstown.

Nominations Committee: W. J. Nordley, Edgeley, *chairman;* M. L. Lovell, Beach; S. K. Svenkeson, Minot.

Convention City Committee: O. C. Anderson, Jamestown, *chairman;* E. J. Pearson, Minot; S. T. Monek, Jamestown.

Clow Award Committee: W. J. Nordley, *chairman;* Weaver Collins, Fort Yates; Lawrence Kirk, Fargo.

Resolutions Committee: L. W. Veigel, Dickinson, *chairman;* John Kleven, Grand Forks; Dave MacDonald, Bismarck.

Constitution Committee: K. C. Lauster, Bismarck, *chairman;* E. A. Tschida, Dickinson; Louis Lavey, Jamestown.

Time of Meeting Committee: S. P. Ravnos, Mandan, *chairman;* Harry Lundquist, Minneapolis; Bill Kuether, New Salem.

On motion of S. Ravnos and second by S. Calvelage, the meeting was adjourned at 12:15 P.M.

The meeting was called to order at 12:45 P.M. at the noon luncheon on the following day by President Jenson. Mr. Jenson called for remarks by L. K. Clark, Conference secretary on active duty with the Army. Mr. Clark responded with a brief discussion of sanitation work in defense areas.

Report of the Nominating Committee was called for by the president. W. J. Nordley presented the report nominating the following: E. J. Pearson, Minot, *President;* S. T. Monek, Jamestown, *Vice-president;* H. G. Hanson, Bismarck, *Secretary-Treasurer.* Mr. Pearson and Mr. Monek accepted and the secretary accepted with the understanding that his term of office continue only until the return of Mr. L. K. Clark, former secretary, on active duty with the Army.

Meeting adjourned at 1:30 P.M.

Meeting was called to order by the new president, Mr. Pearson, at 1:50 P.M., October 15.

The business session proceeded with the call for reports of the committees.

The Constitution Committee report was given by K. C. Lauster. Changes necessary in the sewage section clauses were explained and the report of the committee was recommended for adoption. Mr. Lauster called attention to the value of the *Sewage Works Journal* to sewage works personnel and discussed the new "operator's corner" section of THE JOURNAL. It was moved by K. Riley and seconded by Dean Chandler that the report be adopted and changes be made in the constitution.

The Resolutions Committee brought in nine resolutions and recommended same for adoption. Motion by W. Nordley and second by Dean Chandler carried. The secretary was instructed to furnish copies of resolutions to the press and other persons as indicated.

The Auditing Committee report was given by President Pearson in the absence of Chairman H. Hintgen. The report of the financial condition of the organization as presented in the financial statement of the secretary was recommended for approval. Adoption of the report was moved by W. J. Nordley and seconded by J. Morrissey. Motion carried. The secretary was instructed to file statement as approved and signed by the committee.

The Time of Meeting Committee report was given by S. Ravnos. A date not earlier than the middle of September and not later than the middle of October was recommended. The first of the week and middle of the month appeared to be the most favored time in the discussion following. Dean Chandler moved that the next meeting be about the middle of October at such time as the Executive Committee shall decide. Second by R. Jenson. Motion carried.

The invitation of the City of Williston for the next meeting was read by the president. W. Robinson extended a further invitation from Williston. Lee Ottaway extended the invitation of Devils Lake and R. M. Jenson that of Grand Forks.

A brief discussion of the new Public Works Reserve was given by Lee Hughes, State Director.

Following a report of the progress of the certification program by the president of the Board, S. Ravnos, the president called for further comments by the secretary. The classification of operators and plants and the alternate plans being considered by the Board were explained. The flexibility of the certification process wherein the Board may issue a certificate on the basis of the application alone if it considers the evidence of qualifications satisfactory, was discussed. In cases where examination is deemed advisable, three plans are under consideration:

1. Publishing of 100 representative questions for each class of operators in the Official Bulletin during the coming year. Certificate to be issued on the basis of written examination or material covered in presence of Board member or responsible city official.
2. Certificate to be issued on the basis of written examination following attendance at two short schools if such can be arranged at one of the State colleges.
3. Certificate to be issued on basis of satisfactory completion of course to be given by extension division of State college if a course at reasonable cost can be worked out.

Operators were encouraged to submit applications even though final procedures for action on all cases had not been worked out completely. Operators apparently have been withholding applications pending more definite information on preparation and actual certification requirements. Fifteen applications have been received by the Board to date.

The Convention City Committee report by S. Monek recommended Williston for next year's meeting. J. Kleven moved adoption of report; R. Jenson seconded. Motion carried.

S. Ravnos moved that the staff of Official Bulletin be permitted to suspend publication of the October issue in view of the extra work placed on the staff in preparing for the Convention Issue and for the convention itself. Seconded by R. Jenson. Motion carried.

H. G. Hanson, *Secretary*

NORTH CAROLINA SEWAGE WORKS ASSOCIATION

Twenty-first Annual Convention, High Point, North Carolina, November 3–5, 1941

The twenty-first annual joint meeting of the North Carolina Sewage Works Association and the North Carolina Section American Water Works Association was held November 3–5 in the Sheraton Hotel, High Point, North Carolina. More than two hundred and fifty water and sewage works men from North Carolina and adjoining states gathered for a typical North Carolina entertainment program including a barbecue, luncheon, banquet, dance, and inspection trips. The technical program was so arranged that suitable papers were read and discussions held on both sewage and water treatment. More than sixty manufacturers and representatives took part in the meeting and displayed their materials in an exhibit area covering approximately 2000 square feet. Professor Harold B. Gotaas of the University of North Carolina was Chairman of the Program Committee.

Mayor O. Arthur Kirkman delivered a cordial address of welcome on behalf of the city. Mr. A. O. True, Chairman, responded with the Association's thanks. Mr. True presided at all of the meetings.

Description of High Point Treatment Plants

James Aubrey Setzer, superintendent of water and sewage treatment, gave a paper on the treatment facilities at High Point. Mr. Setzer detailed the history, construction and engineering facilities of the 2 M.G.D. West Side activated sludge plant. This plant is located about six miles west of High Point and serves four outfalls leaving the city. The plant includes screening, grit removal, pumping, activated sludge, final sedimentation, and vacuum sludge filtration. Sewage treated averages 1.5 M.G.D. and is of medium strength having a B.O.D. of 200 p.p.m.

The East Side plant is of the trickling filter type with separate sludge digestion, and is located about six miles east of the city. The facilities include screening, grit removal, primary settling, trickling filters, secondary settling and separate sludge digestion with sand drying beds. This plant serves about two-thirds of the city's population and treats most of the trade wastes from the manufacturing plants.

Inspection Trips

Many of the delegates attended the inspection trips arranged by J. L. Perkins, Director of Public Utilities at High Point. A trip through one of the world's largest furniture factories and showrooms was included in addition to tours through the water and sewage treatment plants. A separate inspection tour through the furniture factories was arranged by the local ladies committee.

Federation President Speaks

Arthur S. Bedell, President of the Federation of Sewage Works Associations, was the principal speaker at the luncheon held Tuesday in honor of national officers present. Mr. Bedell brought greetings of the Federation to the North Carolina meeting and reviewed the history, purposes and needs for reorganization on the part of the national Federation. He pointed out that the present membership far exceeded the most optimistic hopes of the founders. The organization at present, he felt, was quite adequate to meet the demands that would be placed upon it. More than one hundred delegates and guests attended the luncheon.

Treatment of Sewage Using Intermittent Sand Filters

This paper was read by Robert H. Grady, Assistant Engineer, N. C. Department of Conservation and Development, and included the results of research by the author while at North Carolina State College. The purpose of the work was to determine if it is practicable (1) to reduce costly grading of sand now specified, (2) to decrease the depth of the sand, and (3) to increase dosage rates. Intermittent sand filters are used throughout North Carolina in small communities, schools and other state institutions where something less than expert operation is likely to be accorded the units.

The author used experimental filters constructed of eight-inch terra-cotta pipes suitably provided with gravel and underdrains of standard specifications to simulate actual field conditions. Using sand ranging in effective size from 0.20 m.m. to 0.50 m.m. and uniformity coefficients of 2.0, the author dosed the filters at two rates, namely, 125,000 and 200,000 gallons per acre per day. The study also included sand depths varying from 9 in. to 30 in. Sewage used was domestic in character being obtained daily from one of the state institutions.

The results indicated that sands as fine as E. S. O. 0.30, U. C. 2.0, clogged quickly while sand as large as E. S. O. 0.50 was too coarse to be classified as an intermittent sand filter. Little was gained by increasing sand depths beyond 18 in. The smaller rate of dosage studied (125,000) was more effective though the sand depth is doubled.

Water—A Natural Resource

This paper, by Guy R. Scott, Senior Sanitary Engineer, Tennessee Valley Authority, dealt generally with the problem of industrial stream pollution control and specifically with some work carried on by the Tennessee Valley Authority. Scott pointed out the needs for conservation of our streams by reviewing the present status of pollution controls now existing. The engineering sciences of water treatment and sewage treatment methods must be considered remedial measures which do not lighten the load carried by the streams. These man-made processes have been developed to protect the health and well-being of the communities. No comparable progress, however, has been shown in the field of industrial waste treatment. Processes must be developed which can economically return our streams to their natural state of purity.

The author points out that although assistance has been forthcoming to towns for the treatment of sewage, no similar help is available to the industry responsible for the town's growth. A cooperative research program under central agency with federal assistance is indicated.

Since 1936 the Tennessee Valley Authority has been conducting stream pollution surveys in order to determine the needs for future control. It has received the assistance of health departments in seven states and the U. S. Public Health Service. The work has included studies of the four critical sections on the Tennessee River and tributaries. The work on the streams included weekly samples which were examined and results tabulated for one year in most cases. All industries were surveyed and data obtained on processes, quantities of materials and amounts of wastes. These data are now being assembled and tabulated. Full access to these studies will be given to the states' agencies and the success of the plans developed will depend upon the interest of the states concerned. Uniform regulations and sound policies of administration must be adopted or the Tennessee Valley is likely to become as grossly polluted as other industrial drainage areas.

Some Legal Aspects of Sewage Treatment

Grover Jones, City Attorney, High Point, N. C., reviewed the rules laid down by the Supreme Court of North Carolina with respect to municipal corporations and sewage treatment. The Court has repeatedly held that where damage results to land the injury is considered a taking or appropriation of the land and compensation must be awarded, but that a plant so operated cannot be enjoined from operation for injuries that may happen to land. The land owner can bring suit for damages to the land in the past, present, or future. The right to pure air is held to be the same as the right to pure water. In any given case the jury's duty is to determine the "Amount of the Taking" of natural property rights of the land owner.

The author stated that in his experience with many cases, it has been his observation that land owners and their witnesses are so prejudiced against the location of sewage treatment plants that they are given to "most reckless and malicious swearing." The right to trial by jury is guaranteed by the constitution in these cases, which is unfortunate. Verdicts by juries usually are prejudiced in favor of land owners; and do not always take into consideration facts by expert witnesses. The author held that reference of these cases has been most helpful, since the matter is then tried before a jury upon the facts found by a referee. Counsel for the municipality and land owner must mutually agree to such a procedure beforehand, however.

The author strongly recommended state legislation which would grant the State Board of Health (or a commission) full power and authority to make preliminary investigations prior to the bringing of any suit by land owners. Land owners would be required to submit the matter to the Board prior to bringing the suit. Such a law would tend to enlighten land owners of processes employed and would discourage suits where no real basis for suit exists.

The convention adjourned Wednesday, November 5, following the adoption of a new Constitution and By-Laws and the election of officers. The new officers for the coming year are:

Chairman: D. M. Williams, Durham, N. C.
Vice-Chairman: W. J. Parks, Jr., Camp Davis, N. C.
Secretary-Treasurer: R. S. Phillips, Durham, N. C.
Director: H. G. Baity, Chapel Hill, N. C.

R. S. Phillips, *Secretary*

Reviews and Abstracts

REPAIR OF WAR DAMAGE TO SEWERS

The Surveyor, 100, 17–18 (July 11, 1941)

Repairs to sewers damaged by bombings are recommended by the Ministry of Health to be cared for by two parties, one party comprising six men including a foreman to rope off craters, clear debris, etc., and a larger party of ten or more workmen for carrying out repairs. Repair parties are considered important enough to defer the calling up for war service of the men who are engaged in this work.

Adequate travelling facilities are felt to be essential.

Allocation of personnel to districts is not recommended as the bombings are rarely evenly distributed. After bomb damage has been done the work of repair is parcelled out as fairly as possible and with a view to avoiding unnecessary travel.

General recommendation for inspecting the damage include:

1. An inspection by a technical assistant to determine and make record of the damage.
2. Unless a bomb actually falls on the sewer it is unlikely that damage will be caused to a sewer located deeper than the bottom of the crater. If a bomb falls directly over the pipe line, the earth may be forced down, causing a fracture.
3. However, bombs splinter and sometimes carry down 20 feet below the bottom of the crater causing damage. Thus a complete inspection is necessary even in a shallow crater.
4. Generally damage extends 10 to 20 feet beyond the crater.
5. Any manhole within 75 feet of a crater must be inspected.
6. Uncradled sewers usually suffer no more than those encased in concrete.
7. Damage may not show up promptly, thus requiring another inspection.

Temporary repairs are not recommended except (*a*) when a crater must be filled promptly for any reason, (*b*) when a large number of sewers are damaged at the same time and insufficient labor is available to repair all damage at the same time, or (*c*) when shortage of personnel and materials would delay permanent repairs for a long time.

Concrete cradles, steel, or spun-iron pipes are recommended for repairs, as is very careful backfilling.

The most commonly used methods of dealing with the sewage flow are:

1. Shutting off the flow at the next upstream manhole and pumping out of the sewer.
2. Exposing the ends of the fractured line and cutting a channel through the crater to carry the flow.
3. Allowing the sewage to percolate into the soil.

The ministry of Health requires certain information to be kept of the damage, as follows:

1. Situation.
2. Date of damage.
3. Extent and nature of damage.
4. Cause of damage.
5. Original construction.
6. Construction after repair.
7. Date of commencement of repairs.
8. Date of completion of repairs.
9. Cost of repairs.
10. Foreman in charge.
11. Technical assistant in charge.

Speed in carrying out repairs is considered essential to the public health and morale in accordance with the policy of removing evidence of war damage as quickly as possible.

K. V. Hill

REPORT UPON THE COLLECTION, TREATMENT, AND DISPOSAL OF SEWAGE AND INDUSTRIAL WASTES OF THE EAST BAY CITIES, CALIFORNIA

By C. G. Hyde, H. F. Gray, and A. M. Rawn

Planograph 549 pp., 104 plates. June 30, 1941

This is a comprehensive report, made with the cooperation of seven cities, on the problems of sewerage and sewage disposal of the cities of Alameda, Albany, Berkeley, Emeryville, Oakland, Piedmont, and Richmond. These cities discharge sewage directly or indirectly into San Francisco Bay, a tidal water, containing around 15,000 p.p.m. chloride, with a volume of about 2,900,000 acre feet. Rainfall is largely confined to the five months, November to March, averaging annually 23.31 inches, of which 4.34 inches fall in April to October, inclusive.

The shores and shore waters have become very foul; unsuitable for bathing, and hardly utilizable for boating, fishing, and the like. The problem is one of aesthetics, not public health.

The tidal prism has a total daily supply of dissolved oxygen around 35,000,000 pounds. The B.O.D. of the East Bay area sewage is estimated at 84,000 lb. for 1940 and 145,000 lb. for 1965. The oxidizing capacity of the Bay waters is so great that if properly utilized, treatment by short-period subsidence with grease removal will suffice. Depth and strong currents are readily reached at a reasonable cost.

The East Bay area is about 20 miles long and 4.5 miles wide, including a land area of 87.36 sq. mi., of which 24.1 sq. mi. are in parks, heavily industralized areas or in other areas in which little population development is anticipated. Certain additional areas may be included, amounting to 30.2 sq. miles. The population is estimated at—

Area	1940	1965	1990
9 Cities	492,000	720,000	779,000
Entire Area	508,000	776,000	944,000

The 1940 population is all connected to the sewers, except for 8,000 people. The water consumption is around 76.7 gal. per capita per 24 hour. Of this, 65 per cent of the domestic consumption was assumed to reach the sewer, and 90 per cent of the industrial consumption. Many of the existing sewers are poorly constructed. The sewage is discharged through 60 outlets. Of the 35 principal outlets, 18 serve combined sewers. Infiltration tests showed from 600 to 2,000 gal. per acre per day. The domestic sewage is moderately strong, analyses showing as follows:

Constituent	Parts Per Million		
	Average	Observed Maximum	Observed Minimum
Suspended Solids	293	900	4
B.O.D.	284	700	7
Grease	52	154	5

The area has 411 diversified industries, of which 135 were visited. The flow of 27 establishments was gaged.

A large number of float tests were made to determine the currents in the bays. Sewer gagings were also made at 11 stations.

Analysis of the cost data shows that seven of the cities at least should join in a combined project. The Richmond area problem is not so acute and may be deferred for a few years.

Financing by 40-year 3 per cent bonds is recommended, with a general obligation not revenue bonds.

All temporary relief measures are beyond the current or annual financial resources of the seven cities.

The Board recommends that all surface waters be removed from the sanitary sewers.

Either air-dried digested sludge or 70 per cent moisture filter cake can be sold in a local market for around $10.00 per dry ton. Heat-drying is not warranted, with a sludge containing only 2 per cent nitrogen. Sludge gas may also be utilized for power production. The value of all by-products is relatively low, around 7 per cent of the annual cost.

Twenty-four projects were studied, divided into groups according to the principal city served; 3 serving Richmond; 4 serving Berkeley; 16 serving Oakland; and one serving Alameda. Project K is recommended for immediate action, leaving the Richmond area until later. Project K is estimated at $6,886,000, itemized as follows:

Item	Estimated Cost
Intercepting Sewers and Force Mains	$2,801,000
Diversion Structures	80,000
Pumping Stations	361,000
Treatment Works	1,391,000
Outfalls	945,000
Land, Right of Way, etc.	160,000
Total	$5,738,000
Engineering and Contingencies, 20 Per Cent	1,148,000
Grand Total	$6,886,000

This is to serve a 1940 population of 453,680, with a flow of 29.6 m.g.d. and a future population in 1965 of 632,400, with a flow of 47.5 m.g.d.

The estimate includes interceptors, 126,400 feet, from 10 to 84 inches; force mains, 10,400 feet, from 10 to 54 inches; outfalls, 13,400 feet, from 72 to 90 inches in size.

Special investigations are detailed on chemical precipitation of sewage and the phenomena of dilution in tidal waters. If a pipe outlet is designed and located so as to afford a dilution ratio of 225 to 1 before the mixture of sewage effluent and Bay water can reach shores or areas of confined waters, no nuisance or health menace need be feared. This condition can be met in the East Bay area.

The industries found include fruit and vegetable canning, dairy products, beverages, laundries, paint and chemical works, roofing paper, packinghouse, soap, tanneries, wool pulling, vegetable oils, yeast and vinegar plants. An interesting table of population equivalents is given.

The report contains numerous tables, charts, and diagrams covering local data prepared for reference in design.

Langdon Pearse

HORSHAM SEWAGE WORKS

By Arthur Marshall

Civil Engineering (London), 36, 517, No. 421 (July, 1941)

The population of Horsham prior to the war was about 15,000 but due to the advent of evacuees the figure is now about 20,000. Prior to 1933 the sewage had received land treatment. During that year sedimentation tanks and filters were provided, with drying beds for sludge. Due to complaints concerning odors from these beds the Urban Council decided, in 1938, to try the "Porteous Process" for sludge treatment. At the same time the plant was modified and additional filters added.

The present plant consists of bar screens with 1 in. clear openings, five sewage pumps, two grit chambers, four settling tanks, seven circular filters and three humus tanks. The four settling tanks provide a 10 hour detention period. They are arranged in two groups, the tanks in each group operating in series. The filters are dosed at a rate of 80 gal. per cu. yd. of media per day. Humus sludge is drawn by gravity to the pump sump and resettled in the settling tanks.

The sludge treatment plant was designed to treat 4,000 gal. of primary sludge at 95 per cent moisture in an 8 hour day. It consists of: (1) Three high-pressure heating vessels for sludge; (2) A heat exchanger or coacter for recovery of heat; (3) Two decanting vessels for the settlement of treated sludge; (4) Two filter presses for producing sludge cake; and (5) A steam boiler for generating steam for the heating process.

Other equipment includes necessary pumps and a disintegrator for reducing the solids to small size before the heat treatment.

Raw sludge is pumped through the heat exchanger, wherein the temperature is raised to about 280° F. to the heating vessels. Each heater treats about 250 gal. per batch. Heat is applied by means of a steam circulating jet in the base of the heater. Gas released during the cooking process is passed through a coil in the boiler feed tank to recover heat. Condensate is passed to the main sewage pump chamber, and the remaining gas is discharged under the boiler fire.

Treated sludge is discharged to two hopper bottom decanting vessels. Here the supernatant is drawn off and conveyed to the sedimentation tanks. The sludge is thickened by motor driven mixers and passed to the filter presses.

Each of the two presses has 25 cavities 24 in. square by 1 in. thick. Between 600 and 700 lb. of cake are produced per press. A pump is used to force thickened sludge into the press. A combined displacement and air vessel is connected to the discharge side of the pump. As the cake forms and the resistance builds up part of the sludge is forced into the vessel, compressing the air. When the pressure reaches 100 lb. per sq. in. the pump stops and the press is fed from the tank until the pressure falls to a predetermined level, at which point the pump is automatically started again. This cycle is repeated until the pressure ceases to fall. Filtrate from the press is discharged to the main sewage pump sump.

Pressed cake is stacked in the open air, or roughly broken up and piled into heaps to become dry. With a moisture of 15 per cent or less it is considered suitable for use as a fuel. There is insufficient cake produced to provide a continuous supply of fuel, and coal or coke is used to augment the supply.

Results for one week in March, 1941, show the following data.

FUEL USED:
- Coke, 26,200 pounds per day.
- Sludge cake, none.

Hours Duty (5 days).
- Boiler, 11 hr., 37 min. (per day).
- Plant, 8 hr., 44 min. (per day).

Number Heat Batches (5 days).
- 19 per day.

Temperature, Deg. F.
- Raw sludge, 53.6.
- Heaters, high, 363.2; low, 334.2.
- Heat exchanger, pre-heated, 286.7; treated, 178.3.

Sludge Treated.
- 4,717.6 gal. per day.

Filter Pressings.
- Number, 3 per day (6 days).
- Press time, 4 hr., 34 min.

Records show that between the first week of August, 1939, and the last of April, 1941, the plant has operated 334 days and has successfully treated 1,412,263 gal. of sludge with an estimated moisture content of 96 per cent. The average output per working day was 4,228 gallons. The weight of cake produced was 356 tons with an estimated average moisture content of 40 per cent.

The personnel employed at the plant number 2 boiler attendants and two panel operators. It has been found necessary to operate the plant on a two shift basis. The duty hours of both stokers and panel men lap at certain periods and it is during these times that the two spare men carry out the work of unloading the presses, plant cleaning, and other work. The plant is operated 5 days a week and repair and overhauls are carried on during week ends.

T. L. Herrick

RECONDITIONING OF EXISTING SEWER AT REIGATE AND REDHILL, SURREY

The Surveyor, 100, 107–108 (Sept. 26, 1941)

This article describes the rehabilitation of trunk sewers in the Borough of Reigate. The sewers which were egg shaped varied in size from 2 ft. 4 in. × 3 ft. 6 in. to 2 ft. 8 in. × 4 ft. were built of 1 or 2 rings of brick in the years 1865 to 1875.

Sewer failures leading to the rehabilitation comprised distortion of shape, bad cracks at the springing line and soffit, settlement, open joints, silting, infiltration and root growths. Some 7,400 feet were rehabilitated.

Two methods of repair were used. The first method, later abandoned, consisted of spraying, in place, a 1½ in. layer of mortar (1 part cement, 3 parts sand) against the old brick work. The section was reinforced by 3/16 in. 3 × 3 electrically welded steel mesh. The gunite was placed 2 in. thick in the invert and for a height of 1 ft. 6 in. above the invert.

The second method involved the use of two gunite precast sections manufactured outside the sewer. The crown section was placed first (supported in place by spikes driven into the brickwork) and followed by the invert section. Spaces between the two sections were then joined together by guniting. The annular spaces between the sewer and the linings were filled with gunite under pressure through holes provided in the linings.

Sewage flow during the work was cared for by pumping.

The second method of construction proved to be the easier and cheaper.

K. V. Hill

MODIFIED PHOTOELECTRIC PHOTOMETER FOR COLORIMETRIC DETERMINATIONS IN WATER AND SEWAGE LABORATORIES

By William D. Hatfield and George E. Phillips

Industrial and Engineering Chemistry, Anal. Edition, 13, 430 (June, 1941)

The photoelectric photometer has been modified to suit the requirements of the water and sewage laboratory.

The photometer is a vertical type instrument using either one of two photoelectric cells and a low form 100 ml. Nessler jar which is marked for inside depths of 25, 50, 75, and 100 mm. Excellent results were obtained with either the single cell or double cell balanced unit. However, because of fluctuations in light intensity with variations in line current, the unit using a single cell is tedious in operation. The balanced circuit is free from such fluctuations. The correct light filter, and the optimum working depth was determined for each analytical test. Light transmission curves were developed for the determination of turbidity, H-ion concentration, dissolved oxygen, residual chlorine, iron, and ammonia, nitrite and nitrate nitrogens.

Complete wiring diagrams and specifications of material are given in detail in the article.

E. Hurwitz

QUANTITATIVE DETERMINATION OF DISSOLVED OXYGEN

By Robert T. O'Connor

Industrial and Engineering Chemistry, Anal. Edition, 13, 593 (Sept., 1941)

A quantitative method for dissolved oxygen based on its reaction with reduced ascorbic acid added to the liquid is reported in this paper. Ascorbic acid oxidase extracted from cucumber or cabbage juice is used as a catalyst. The reaction is effective within a pH range of 5.0 to 7.5 and is complete within 5 to 15 minutes at 25° C. The method is adapted particularly to determination of dissolved oxygen in milk and while it gives results that compare favorably with the Winkler method on water samples, its application is cumbersome and the number of determinations which can be performed per half day under most favorable conditions is limited by the author to thirty. Therefore it offers no advantage over the Winkler method to the chemist working with water and sewage. Details of the procedure and a description of a special piece of glassware required for its application are given in the article.

E. Hurwitz

SULFAMIC ACID MODIFICATION OF THE WINKLER METHOD FOR DISSOLVED OXYGEN

By Stuart Cohen and C. C. Ruchhoft

Industrial and Engineering Chemistry, Anal. Edition, 13, 622 (Sept., 1941)

Nitrites react with sulfamic acid to yield nitrogen and sulfuric acid:

$$NH_2SO_2OH + HNO_2 = H_2SO_4 + N_2 + H_2O.$$

On the strength of this reaction a method using sulfamic acid for the destruction of nitrites in the determination of dissolved oxygen and biochemical oxygen demand has been developed. Experiments indicate that sulfamic acid is best used as a preliminary treatment. The solution is prepared by dissolving 4 grams of the acid in 50 ml. of distilled water and adding 50 ml. of cold 40 per cent sulfuric acid. One ml. of this solution is used as preliminary treatment for destruction of nitrites in a 300 ml. dissolved oxygen sample bottle. (This quantity will destroy 19.3 p.p.m. nitrite nitrogen.) After addition the bottle is stoppered and shaken and allowed to stand 10 minutes. From this point on the procedure is identical with that of the azide modification.

The addition of sulfamic acid to the alkaline-potassium iodide solution was shown to be ineffective because the sodium sulfamate formed does not remove nitrites and the sulfamic acid produced after acidification was not effective in the presence of iodine. The addition of sulfamic acid to the manganous sulfate solution was ineffective in the removal of nitrites from solutions containing large amounts of organic matter.

The use of sulfamic acid was satisfactory for B.O.D. determinations and prevents biochemical oxygen demand when necessary to store dissolved oxygen samples for a short time.

E. Hurwitz

WATER POLLUTION ABATEMENT IN THE DELAWARE RIVER BASIN WITH SPECIAL REFERENCE TO THE CITY OF PHILADELPHIA

A Symposium Published by the Interstate Commission on the Delaware River Basin, Philadelphia, Pennsylvania, 1941

I. The Interstate Program—By Hon. E. J. Turner

The pollution of the Delaware River arising from Philadelphia is of reasonable concern to others, both within and outside of Philadelphia as well as to Incodel. This problem of pollution abatement is not new but has been discussed for over half a century. The city discharges approximately 350 million gallons of raw sewage into the Delaware and Schuylkill Rivers and this affects other communities in Pennsylvania as well as in New Jersey. Communities in the Delaware River Basin both above and below Philadelphia have constructed and are maintaining sewage treatment facilities and are demanding that their source of water supply should be protected from pollution by Philadelphia. It is therefore Incodel's concern to campaign for the completion of Philadelphia's program. It is also to the interest of the people of Philadelphia to have this program completed in order to get a safer and more palatable " water supply for domestic purposes and more adequate supply for industrial purposes, to enhance the values of real estate lying along the banks of their streams, to protect navigation interests and port development and to stimulate recreational uses of the streams. Financing of the project should be done by a sewer rental system. No further survey or study is necessary as all the facts and factors dealing with the pollution of Delaware and Schuylkill Rivers by the City of Philadelphia are known.

The pollution of the Schuylkill River is mainly from acid mine drainage. The production of coal in this anthracite region of Pennsylvania fifty years ago was as great as it is now, but the conditions now in the river are worse because of the cumulative effect during this period. In order to develop a long-range program of preventive and corrective measures in connection with mine drainage waste, the Incodel has offered its services as a coordinating agency for unified city-state-federal planning to correct the conditions in the Schuylkill because of the interstate nature of the problem. It is suggested that an advisory group of qualified technical experts representing the three levels of government as well as the anthracite industry be selected:

1. To review the facts.
2. To develop a long-range plan of action.
3. To settle upon proper allocation of costs.

II. The Philadelphia Program—By J. H. Neesson

With the exception of the portion of the Northeast treatment works now in service, construction has been confined to the collecting system. This was done to permit research for a type of sewage treatment applicable to the needs of Philadelphia and at an operating cost within its resources. Capacity must be provided for a daily average flow through the treatment works of seven hundred million gallons and a storm flow of one billion two hundred million gallons.

When the Northeast works was constructed in 1923, Imhoff tanks were the best and most economical treatment process known but due to the large quantities of industrial wastes in the sewage interferred with the digestion process.

After tests and observations made of various developments in treatment processes during the past twelve years, it is felt that the requirements will be best met by an aeration process. By this process the degree of purification can be varied by varying the air contact as required by conditions in the river. Solids settled out in the sedimentation tanks will be digested in separate heated tanks and the gas collected. The Imhoff tanks at the Northeast works will be changed over to plain sedimentation tanks. The Sanitary Water Board required a degree of treatment higher than plain sedimentation at the Northeast works and the other projects should be so designed that the degree of purification could be increased when found necessary.

As a first step in the work it is proposed to change over the treatment process at the Northeast works and increase the capacity of the works to 125 m.g.d. The total future capacities will be 300 m.g.d. at the Northeast works, 250 m.g.d. at the Southwest and 150 m.g.d. at the Southeast plant.

Philadelphia Authority has made application on the sewage disposal program for grants to the Federal Emergency Administration of Public Works. These applications were refused by federal authorities because the funds were depleted. Since then several attempts have been made to establish a sewer rental charge sufficient in amount to carry a bond issue of $42,000,000. The first bill was based on a flat charge of 1¼ times the water rent to yield $7,500,000. This was objected to, both by industry and real estate owners which resulted in a substitute bill, the basis of which was 4 mills on the dollar of real estate assessment to yield $7,800,000. This ordinance was approved, passed by the Lower Court, the decision being reversed by Pennsylvania Supreme Court. Finally the Council reported a new formula—a minimum of 3 mills on assessed values of property served plus one-fourth the water rent. This plan also was rejected by the courts. A number of other plans are under consideration now.

III. The Need—By H. B. Vaughan

The Delaware River at Trenton, the head of the tidal portion of the river, is relatively clean indicating over a period of two years an average of 95 per cent dissolved oxygen saturation. Between Trenton and Frankford Creek, Philadelphia and Riverton, Palmyra on Jersey side, the river is lightly polluted. From these two points down to Eddystone, Pennsylvania, a distance of 22 miles the Delaware River is subject to gross pollution. There is only an average of 8 per cent dissolved oxygen saturation in the river waters during the warm weather months. The cities of Philadelphia, Camden and Gloucester representing over two million inhabitants discharge raw sewage into the river in this zone, of which 88 per cent is contributed by the city of Philadelphia. In the city of Philadelphia alone, 90,000 tons of solid industrial wastes are discharged into the river annually. These consist of distillery, dye, bleaching, tannery, dairy, laundry, oil, pickling, wool scouring, slaughter house and other wastes. Wastes from 40 to 200 industrial establishments are discharged directly into the river while the balance are discharged into the city sewers. The total sewage and industrial wastes deposited from the rivers is 200,000 tons annually from the City of Philadelphia.

The Schuylkill River in this zone from Frankford Creek to Eddystone aggravates the situation by the pollution derived from coal mining and sewage wastes. The amount of coal fines going into this stream was 1,000,000 tons in 1939. Twenty-four million tons of culm wastes are in the bed of Schuylkill River. The result of all this pollution is (1) serious damage and corrosion to vessel hulls and paints. Philadelphia is often not made a port of call for ships for this reason. The Delaware water is useless for boiler water without treatment and undesirable as ballast. (2) The morale and efficiency of workers along the river bank in the shipyards and navy yard is affected by the offensive odors produced. (3) Waterfront property values are affected. (4) Sources of water supply for waterfront industries are impaired. (5) The quality of raw water for the public water supply is impaired so that the palatability and the odor of the treated water have much to be desired. (6) The normal recreational uses of the rivers are destroyed. (7) It cost the Federal Government and the City of Philadelphia in the year 1939, $1,000,000 to pump sewage, industrial waste and culm from the Schuylkill River alone.

IV. The Implications—By A. Wolman

The City of Philadelphia discharges a great quantity of sewage and industrial wastes. This problem is not peculiar to Philadelphia alone but is common throughout the United States. The technological knowledge for the solution of this problem is quite advanced. The concept of local antonomy carries with it the corrollary of local responsibility. States and communities adjacent to Philadelphia might wonder about local autonomy when the fundamental obligations have been neglected for so long. There have been financial, moral, and political delinquencies for a long time. The accomplishments up to the present have not been great enough to meet the need. The lack of money is not a good excuse for the neglect of this problem. The major responsibility of the pollution of this river basin is unquestionably due to Philadelphia. Philadelphia is the only city of the seven largest cities in the United States that has done relatively nothing. Why did the request for grants and loans from P.W.A. not come before 1938 when the P.W.A. program was practically finished? This raises the question as to whether the city has exercised reasonable diligence in correctives. The loss if converted into dollars and cents created by the lack of correctives would add up to a figure far greater than the proposed cost for correctives. The effect on the public water supply has been such that it has become increasingly difficult not only to protect the city against disease but to make it palatable enough so that people will drink it.

The measures taken within the last few years in financing the program which has been referred to as sewer rental, are as the courts have since decided in fact only property tax and not sewer rental.

It is easier to find money for public works such as highways, bridges, tunnels, which are necessary for community life and which are tangible and aesthetic, than for sewage treatment works that nobody sees or cares about except when the sewage begins to contaminate the water supply and create offensive conditions. The city has spent per capita per year for capital costs for sewerage and sewage treatment only about fifteen cents as against other cities half the size, of a dollar and sixty cents.

The depression occurred everywhere in the United States and it was during this period that the greatest advances in municipal sewage treatment plants took place.

The fiscal situation can be met by an outright sewer rental or by pay-as-you-get principle. The latter method will probably result in slowing up the program. The creation of the Sanitary District Authority covering the metropolitan area of Philadelphia to deal with both water and sewer problems is also a good possibility as a device for meeting the financial situation as well as creating an administrative structure.

The State of Pennsylvania has also a responsibility and if there are financial disabilities both the state and the municipality are culpable. State grants-in-aid should be available in addition to Federal grants which even today are a possibility through the Lanham Act. This Act has a provision which permits the leasing of a system to a community thus avoiding the difficulties of indebtedness limitation.

If the States of New Jersey and Delaware entered suit in the United States Supreme Court against the State of Pennsylvania and the City of Philadelphia for ruining an interstate stream, the case would win.

The following two resolutions were passed by the Incodel: (1) That the Sanitary Water Board of Pennsylvania institute legal action to prevent the continued discharge of untreated sewage into the waters of Delaware and Schuylkill Rivers by the City of Philadelphia. (2) That the water pollution problem of first priority is the construction, maintenance and operation of adequate municipal sewage collection, treatment and disposal system and further the immediate resumption of work in carrying forward to speedy completion of Philadelphia's plan of domestic waste disposal is the most important project in the entire Delaware River Basin.

H. Heukelekian

THE INFLUENCE OF SEWAGE TREATMENT UPON THE BACTERIAL POLLUTION OF NEW HAVEN HARBOR

By G. Feldman and C.-E. A. Winslow

American Journal of Hygiene, 34, 91–101 (1941)

The object of the investigation was to determine the effect on the bacterial content of the harbor waters of the two new sewage disposal plants that have been put in operation since 1928 when the last study of the bacterial pollution of the bathing-beach waters of New Haven was published. In 1928 all the New Haven sewage was discharged untreated. At present, between forty and fifty per cent of the sewage entering the harbor has received some treatment by chemical precipitation or by plain sedimentation and chlorination during the bathing season.

The same technic and sampling stations were used in this survey as in the previous one. Twenty-one sets of samples were collected between February and June 1938, twelve prior to and nine after, the chlorination season. In addition, samples were collected during the period when sewage was being by-passed because of the damage caused to the plants after the hurricane of September 21, 1938.

Bacteriological analysis consisted of inoculations into lactose broth fermentation tubes and confirmation on eosin-methylene blue plates. Direct plating on the eosin-methylene blue agar and total counts on agar plates were also made. In the present investigation the check between preliminary enrichment on lactose broth and direct plating on eosin-methylene blue agar was not very satisfactory. Of the samples positive by enrichment in 0.1 ml., 65 per cent were negative by direct plating, an indication of the superior delicacy of the enrichment procedure where small numbers of colon bacilli are present. The average results of the eosin-methylene blue plates checked fairly well with those of the broth enrichment. Only a rough correlation was obtained between the enrichment method and total counts.

There was no appreciable difference in the total plate counts during the 1926–1927 period as against either the winter and summer conditions of 1938. On the other hand, all the tests for *E. coli* show a marked degree of improvement for the winter of 1938 as compared with 1926–1927; and a further marked improvement for the summer period when chlorination was in operation. The percentage of positive enrichment tests in 0.1 ml. portions fell from 39 per cent in 1926–1927 to 24 per cent in the winter and to 14 per cent in the summer of 1938. The percentage of positive tests in 0.01 ml. portions fell from 12 per cent in 1926–1927 to 4 per cent in the winter and 2 per cent in the summer of 1938.

The improvement was much greater in the east shore samples than the west shore samples because the only sewer outlet on the east shore was provided with a treatment plant while the discharge from the Meadow Street and Boulevard sewers on the west shore was not being treated at this time. The west shore samples which showed poor results in the winter showed very good conditions in summer while the east shore samples were slightly poorer in the summer than in the winter. This was attributed to the southerly and southwesterly winds during the summer which drive the sewage back upon the east shore. For the west shore the bad winds are those from the southeast and northeast.

Only at five stations out of thirty was the mean number of *E. coli* during the chlorination and summer bathing seasons over 10 per ml. At most of these stations the high values were due to a count of 100 per ml. on one day. At twenty-three stations a mean value of 3 colon bacilli per ml. was obtained which is considered reasonably satisfactory quality for bathing beaches.

The samples collected after the hurricane when the sewage was being by-passed showed conditions identical with those obtained in 1926–1927.

H. Heukelekian

SUSPENDED SOLIDS BALANCE IN PURIFICATION OF SEWAGE BY ACTIVATED SLUDGE

By C. Lumb

Institute of Sewage Purification Journal and Proceedings, pp. 79–81 (1940)

The purpose of this investigation was to determine what portion of the suspended, colloidal and pseudo-colloidal matter in tank effluent was recovered as excess activated sludge and what portion was lost by oxidation.

Laboratory experiments were conducted with activated sludge on a "fill-and-draw basis." The normal aeration period was about 9 hours during the day with settlement overnight.

Sewages fed were as follows:

Feed A.—Strong sewage settled in the laboratory.
Feed B.—Normal effluent from sedimentation tank receiving acid treatment during the day and plain sedimentation during the night.
Feed C.—Same as Feed B but fitted with a Dorr mechanical flocculator.
Feed D.—Sewage submitted to acid precipitation in the laboratory, settled, decanted, and neutralized.

Operation was maintained with feeds B and C for a total of 13 months with only occasional interruptions. A short period of work with Feed A and D was also undertaken.

Suspended and colloidal matters in the respective feeds were determined. Surplus activated sludge was removed from the aeration systems as necessary to maintain 8–10 per cent in circulation. Dry matter in the wasted sludge was determined. The suspended particles and unchanged colloidal matter in the purified effluents were also determined. The summary of the results is given below:

	Ratio of Sludge Formed to Total Susp. and Colloidal Matter Fed, Per Cent	Ratio of Sludge Formed to Total Susp. and Colloidal Matter Removed, Per Cent
Series A. Feed		
312 p.p.m. susp. and colloidal matter	88.8	102.9
Series B. Feed		
168 p.p.m. susp. and colloidal matter	97.5	107.0
Series C. Feed		
147 p.p.m. susp. and colloidal matter	100.7	107.6
Series D. Feed		
77 p.p.m. susp. and colloidal matter	70.7	96.6

The author concludes from these results that oxidation of the suspended portion of the impurity fed is negligible. In the recovery of the excess sludge no credit is given the dissolved matter in the different sewages, which is removed and utilized by the activated sludge process. If the dissolved matter was included in the solids balance the discrepancy between the total and actual amounts of solids fed and recovered would be greater, giving substantial values for oxidation.

H. Heukelekian

FORMATION OF METHANE IN SEWAGE PURIFICATION

By C. P. Mom

Natuurwetenschappelyk Tydschrift voor Nederlandsch, India, 101, 153–164 (1941)

The author does not believe that methane arises from the direct splitting of acetic acid because if this were so, ethane should arise from the fermentation of proprionic acid instead of methane which is actually produced. Secondly, the reaction $CH_3COOH \rightarrow CH_4 + CO_2 + 2.9$ K Cal produces insufficient energy for methane bacteria. The author considers that Söhngen's reaction is acceptable from an energy and biochemical viewpoint. $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2 + 58$ K Cal. The author accepts the Van Niel and Barker's view that methane arises from the reduction of CO_2 by the hydrogen liberated from alcohols acting as hydrogen donators. He extends this theory to apply for the production of methane from organic acids as follows: $8CH_3COOH + CO_2 \rightarrow 4COOH(CH_2)_2COOH + CH_4 + 2H_2O + 38$ K Cal. CO_2 therefore must play an important part in the chain of process of methane formation. In support of this view, the author calls attention to the generally accepted fact that if the sludge is allowed to assume a slightly acid reaction or if it is stirred strongly and continuously, the carbonic acid content of the gas becomes higher and the methane content lower. Addition of lime during the acid stage of digestion is recognized to be essential for the uninterrupted production of methane.

The author states that in practice the whole process of methane formation is a chain reaction in which the methane bacteria and their symbiotes are brought together onto adsorbing inert particles. Accordingly some work was done to determine the effect of inert particles on digestion which has been indicated by previous workers as being beneficial. Activated carbon was added as inert particles to the daily addition of fresh solids. Four tanks received carbon while the fifth served as control. During the first 21 days, activated carbon was not added to any of the five tanks. During this period the gas production per tank per day was 51.8 liters. During the succeeding 46 days when carbon additions were made, the tank which received 1.25 mg. of carbon per liter gave 28.1 per cent increase in gas production, while the tank receiving 2.5 mg. per liter of carbon showed an increase of 43.2 per cent in gas production. Then the addition of carbon was stopped and it was found that the gas production in all four tanks returned to about that of the control tank. It is not possible to say from this work whether the beneficial influence of activated carbon was due to the adsorption of acids or to the addition of the surface.

H. Heukelekian

SHORT PERIOD MESOPHILIC SLUDGE DIGESTION AT DAVYHULME

By E. Ardern, C. Jepson and L. Klein

Institute of Sewage Purification, *Journal and Proceedings*, pp. 126–130 (1940)

The sludge digestion plant at Davyhulme of the Manchester Corporation consists of four heated Dorr digestion tanks each 200,000–220,000 gal. capacity and two open secondary tanks each about 800,000 gallons. The results obtained during the first year of operation were given in a previous paper; in this one the results of the two subsequent years of operation are given. The main purpose of the plant is to deal with a maximum amount of surplus activated sludge and by digestion and densification to reduce the volume. With this object the proportion of primary tank sludge with densified activated sludge has been kept as low as possible consistent with the production of gas to maintain the required temperature. During the summer it has proved possible to keep this proportion between 15 and 20 per cent. During cold weather it has proved necessary to increase the proportion of primary sludge to 30 per cent and to pass the raw sludge through the digester at a lower rate increasing the time required to feed in the sludge from 10.5 to 15 hours. In this way in spite of the cold weather it was possible to maintain the sludge at the desired temperature. As the plant deals with sludge of low solids content and owing to the separation which take place in the early stages of the process it is possible to remove water or thin sludge at frequent intervals. Previously it was found that the character of this liquor was unsatisfactory if the primary digesters were overflowed to the secondary tanks while the feeding with raw sludge was taking place. Now the liquor is removed 6 or 12 feet below the surface prior to feeding. Withdrawal of denser sludge from the bottom of the tanks occurs about twice a week. Further improvement in the quality of supernatant liquor was obtained by operating the secondary tanks in series.

The detention time in the heated digestion tanks is 12.1 days. The digestion temperature is between 80 and 85 degrees. The yield of gas was 3.4 cu. ft. per pound of dry organic matter added. This volume is less than was anticipated from the operation of pilot plant (5.2 cu. ft.) and less than that obtained under laboratory conditions from the same sludge. It would appear therefore that the recorded volume is much below the actual. It has however proved sufficient for the needs of the plants and a considerable quantity was destroyed as surplus.

A 66 per cent reduction in the volume of raw sludge was obtained by digestion. The dry organic matter reduction amounted to 34 per cent. The pH value of feed sludge varied from 6.2 to 7.0 with an average of 6.7, while the value for the digested sludge (primary) varied from 7.2 to 7.6. This maintenance of alkaline conditions during short-period digestion is largely responsible for the complete absence of foaming. Some of the operation results for the 1938–1939 and 1939 to 1940 period were as follows:

	pH Value	Dry Solids %	Organic Matter %	Grease (chloroform) %	Total N %
Feed	6.6–6.8	3.1–3.2	66.4–66.5	18.8–19.5	3.8–4.0
6 ft. × 12 ft. tanks	7.3–7.4	1.1–1.2	62.1–62.6	11.4–11.9	3.9–3.9
Bottom	7.4–7.4	4.3–4.6	58.6–58.6	9.0– 9.4	3.3–3.4
Secondary	7.5–7.5	6.1–6.6	58.6–59.7	9.0– 9.3	3.3–3.4

The separation of the water in the primary tanks is due to a gradual thickening of the sludge towards the bottom of digester as shown by the following data:

Depth in Feet	Per Cent Solids March 31, 1939	June 28, 1939
6	0.75	1.08
12	0.61	1.10
18	1.65	1.40
24	5.52	4.28
Bottom	5.78	4.77

The thin sludge withdrawn from the higher levels is partly digested and consequently further digestion takes place in the secondary tanks, though their chief function is to permit separation of water.

The sludge from the upper levels of the primary tank is 65 per cent digested, that from the bottom 75 per cent digested and the final secondary sludge 85 per cent digested. These were determined by the gas production from the various sludges under laboratory conditions.

The liquor had an average suspended solids content of 750–900 p.p.m., total solids of 2550–2990 p.p.m. and B.O.D. of 270–280 p.p.m.

H. Heukelekian

SYMPOSIUM ON PRETREATMENT OF TRADE EFFLUENTS

Meeting of the Midland Branch in Birmingham on October 12, 1940

Institute of Sewage Purification, *Journal and Proceedings*, pp. 184–195 (1940)

Contribution by John Hurley

This paper provides a general survey and defines the scope of the subject. The question deals with the pretreatment of trade effluents before discharging into public sewers. The Public Health Act of 1937 compelled the local authority to accept trade effluents in sewers under certain rules and regulations.

The wide variety of effluents derived from different manufacturing processes and even from the same process makes it difficult to formulate a general policy on pretreatment of trade effluents at the factory. Some of the factors to be considered are: (1) The ratio of trade effluent to sewage flow. (2) Possibility of interaction between one trade effluent and another or between a trade effluent and domestic sewage. (3) The nature of the process in use at the sewage works. (4) The size of the stream receiving the effluent from sewage works. (5) The purposes for which the stream was used below the sewage works outfall. (6) What facilities were available for pretreatment at the factory. (7) Did the manufacturer make a payment for the reception of trade effluent?

The nature of preliminary treatment could be classified into two groups: *A*. The recovery of by-products by the manufacturer. Recovery of oil and grease, textile fibers, coal dust and paper pulp might be cited as examples of this group. *B*. For the protection of sewers and sewage disposal works. The discussion is around this latter problem. The pretreatment of trade wastes for the protection of sewers and sewage disposal works might be achieved by: (1) Regulation of the rate of discharge, (2) recording of flow, (3) control of pH value, (4) removal of coarse suspended matter, (5) removal of a specific constituent and (6) reducing the strength of the discharge.

It is difficult to decide what degree of preliminary treatment is necessary in any particular case. The problem offers not only technical difficulties but questions of administration and policy arise such as the anxiety lest manufacturers should be antagonized and leave the district and the need of consistent policy in dealing with various manufacturers in a district especially when they are engaged in the same trade. There is the problem for instance in setting up the By-Laws that if the limiting concentrations are such that the sewage receiving the trade waste is just treatable, a large new factory coming along in the future may make the composite sewage untreatable. Thus where hard and fast By-Laws are formulated it might be necessary to impose fairly high standards of preliminary treatment. The degree of preliminary treatment demanded should be the minimum compatible with reasonable protection to the sewers and sewage disposal works. Every manufacturer discharging a waste into the sewers should make a payment which should have some relation to the nature of the discharge. The price paid could be varied according to the volume and strength. Prescriptive rights must be abolished.

Should the policy of preliminary treatment of trade waste be based largely on local conditions or can it be organized on a national basis? A national basis of solving the problem can be developed by every manufacturer contributing to the central fund a standard amount based on the character and volume of the effluent. Thus whether an industry was located inland or on the coast, the charges payable would be the same. The scheme would be administered for the Central authority by the Local Authorities. From the central fund the local authorities would be reimbursed for treating the trade effluents. The reimbursement to local authority would be according to whether full, partial or negligible treatment is being given.

Contribution by J. McNicholas

Liquor from anodising vats has been sold to paint manufacturers who recovered the barium chromate. It might be feasible to recover chromic oxide from waste plating liquors for the manufacture of green paints. Pickling liquor needs pretreatment because of the great amounts of acid which would affect the sewers and the treatment plant. The wastes should be neutralized to pH values between certain limits (above 6.5). At this value all free acidity is neutralized and also that due to hydrolysis of the ferrous salts. At the sewage plant, the pH value might be brought up higher by lime additions in order to cause complete precipitation of iron. The manufacturers should attempt to dry the sludge produced from the neutralization of pickling liquor waste and dispose of it as scrap. It also might be used as a brown pigment. The sludge from neutralizing tanks might be pumped into underdrained drying beds.

Wastes containing cyanides should be completely excluded from sewage. On the other hand gas works liquor containing greater quantities of cyanide compounds have been received in sewers. Waste from plating in cyanide solutions contain small quantities of ferrous or ferric cyanide. The chromates present in such wastes might help to oxidize the cyanide to cyanate.

Metallic wastes did not affect sludge digestion adversely. The only abnormal feature was that the water decanted from secondary tanks contained large quantities of ferrous iron. Digested sludge contained about 13.5 per cent Fe_2O_3. The dried sludge used as fertilizer has not caused any complaints.

Contribution By C. B. O. Jones

The limits of certain ingredients in trade wastes as contained in Public Health Act of 1937 and the methods of determining the quantities of wastes in the discharges are discussed.

1. Solids in suspension of 300 p.p.m.
2. Oil and grease in excess of 0.5 per cent by volume.
3. Yeast in excess of an amount that would give an oxygen absorbed figure of 150 p.p.m.
4. Sugar in excess of 0.5 per cent calculated as glucose.
5. No tar or tar acids should be discharged.
6. Cyanide compounds in excess of 50 p.p.m.
7. No petroleum, petroleum products or calcium carbide.

The acid wash from the stripping of metals is allowed to drain into a tank containing iron turnings. Hydrochloric acid wash wastes can be neutralized by distributing it over limestones. This method is of no use for sulfuric acid wastes as the limestone becomes coated with calcium sulfate.

H. Heukelekian

SEWAGE GAS FOR POWER

By Walter A. Sperry

Valve World, 38, 127–133, No. 4 (July–August, 1941)

The author states that at the close of 1940 there were 5,400 sewage treatment plants in the United States serving 55,000,000 people or 70 per cent of the urban population. Of this number 4,135 were modern and adequate plants serving 51,000,000 people. The paper continues with a brief discussion of the principles of sewage treatment.

Early use of the gas produced by sludge digestion was mostly for building heat, digester heat and the burning of screenings, but early in the 1920's consideration was given to its use in internal combustion engines.

Sewage solids or sludge accumulates at the rate of approximately 100 pounds per 1,000 persons per day. For Aurora (Illinois) approximately 3.1 tons of sludge solids are collected each day. This sludge has a gas production capacity of approximately 16,000 cu. ft. per ton.

Gas production averages about 50,000 cu. ft. per day or approximately 1.0 cu. ft. per capita per day. The gas composition is about as follows: 32.4 per cent carbon dioxide, 0.4 per cent oxygen, 2.8 per cent hydrogen, 63.0 per cent methane and 1.4 per cent nitrogen. Gross B.t.u. per cu. ft. is 630; net B.t.u. 570. Hydrogen sulfide content is variable but averages from 12 to 24 grains per 100 cu. ft. Compared with 11,000 B.t.u. coal at $3.50 per ton 1,000 cu. ft. of 630 B.t.u. gas is worth 10¢ to 11¢ for heating. Compared with electrical energy at 1.6¢ per KWH, 1,000 cu. ft. of gas is worth about 65 cents.

The initial gas engine installation at the Aurora sewage treatment plant was an 11 H.P. unit which was used for driving a 100 g.p.m. pump. In 1936 additional 75 H.P. gas engine units were added. These engines have earned a gross of $19,209 over purchased power in 57 months of operation. Maintenance cost has been $1,425. Other gas engine generator sets were installed in 1940. These consisted of two 50 H.P. engines direct connected to two 44-k.v.a., 35 k.w., 60-cycle, 3-phase, 440-volt generators. On November 25, 1940, all outside power connections were cut off. Savings accumulated between January 1 and April 1, 1941, over purchased power amounted to $540.

Use of gas engine driven generators for the plant power requirements eliminates the trouble of lightning interruptions, since there are no exposed power lines. The interest charges on the duplicate engine are considerably less than the stand-by charge for purchased power.

Gas is used as follows:

	Cu. Ft. per Day
Pump engines	20,000
Generator engines	10,500
Low pressure boilers for house and digester heat	7,900
Burning of screenings	3,200
Wasted	1,600
Average daily production	43,200

Heat recovery through the exchangers for this period amounted to 37.5 per cent of the total heat in the gas to the engines.

In the engine room all pipe lines are designated according to the following color scheme: fuel lines, red; circulating water lines, blue; exhaust piping and equipment, aluminum; compressed air lines, yellow; current lines, black.

Emergency light is furnished by Coleman gasoline lanterns.

Operating experience has indicated the need for shut-off valves on the engine exhaust lines so that the idle engine can be protected against the return of condensed water derived from the exhaust of the operating engine. The author emphasizes the desirability of equipping all gas lines leading from the digesters to the gas meters with adequate water traps. No hydrogen sulfide scrubbers are used at the Aurora plant and experience to date indicates that when this substance is present to the extent of only 25 grains per 100 cu. ft. or less no injury is caused to the interior of the engines. However, corrosion difficulties were encountered in connection with the operation of the exhaust gas heat exchanger. This was corrected by replacing the original steel tubes with Byers wrought iron pipe and altering the piping design of the exchanger so that it could be operated above the dew point.

Since copper is affected to a considerable extent by hydrogen sulfide, all valves in gas lines should be of the all-iron, lubricated, plug cock type.

The paper is concluded with statistics relating to the use of sewage gas engines and a brief description of various installations.

Paul D. Haney

LABORATORY CONTROL IN SEWAGE TREATMENT PLANT OPERATION

By G. E. Symons

The Canadian Engineer (Water and Sewage), 79, 26, No. 10 (October, 1941)

As sewage treatment processes have become more complex the importance of the plant laboratory has grown materially.

The functions of a sewage works laboratory are: (1) To obtain representative basic data from which a disposal plant can be properly designed, or revised and enlarged; (2) To gather information and collect and record data on the operation of the treatment works, as well as to ascertain the results accomplished; (3) For control of various processes of sewage treatment; (4) To study the receiving body of water in order to ascertain the success of the treatment processes; (5) For testing materials and supplies purchasable; (6) To study industrial wastes; and (7) For research.

Special experiments and analyses are usually made as a prelude to construction.

The recording of data falls into two classes; base data which are original analyses along with flow and volume measurements, and data and quantities which are computed and which represent actual performance figures.

Control of treatment processes is probably the most important function of a laboratory.

No sewage treatment plant should be without a laboratory. In small plants the operator should be trained to carry out the tests necessary to control the operation of the plant. For cities of 15,000 to 75,000 population, one chemist should be employed. The laboratory of the larger plants should be adequately staffed with graduate chemists or sanitary engineers well grounded in sanitary chemistry or biology. Research, development or pilot-plant operation problems should have a competent chemist assigned either to carry on the study or aid in the operating procedure. The laboratory staff should not be burdened with any plant administrative duties. They should be consultants to the operating staff, with the assigned duty and responsibility of maintaining proper control of all processes involving chemistry or biology.

T. L. Herrick

DETAILS OF DESIGN AFFECTING OPERATION OF SEWAGE TREATMENT PLANTS

By C. E. Schwob

Civil Engineering, 11, 541–544 (Sept., 1941)

This article presents the experiences of the author in connection with his work with the Illinois State Department of Public Health and summarizes many pitfalls in plant design as they affect operation. Satisfactory design can only be accomplished by studying the experiences of plant operators and determining from them the proper course for ease of operation and successful results. These observations include the proper arrangement of units to eliminate odors from sewage pump sumps, sludge division boxes, sludge wells, and similar places. It is desirable to provide mechanical cleaning for screens with openings of less than one inch. Operators may have a fear of deep unlighted pits around the sewage plant, particularly if the screens are located in these pits, and if no ventilation is provided. Hydraulic conditions in settling tanks should be such that dead spots are eliminated in approach channels so that sludge will settle only in the tanks. Provisions for available places in sludge draw off lines for rodding is necessary at all of the bends and other places where the operator can break up any material clogging the line. Grease removal should be provided, prior to or in the primary settling tanks. The author recommends the use of sludge concentration tanks for waste activated sludge or supernatant liquor to prevent the need for returning these to the primary settling tanks and increasing the sludge load there. Sludge piping should be cross-connected so that each pump can be utilized for pumping to and from the various units, thus providing maximum of flexibility of operation. In secondary treatment plants involving trickling filters, provision for flooding the filters should be included. The rock should be of such a material that spalling will be practically eliminated, and the rocks will maintain their original size. Dosing tanks generally provide too much retention and too great a time between doses. It has been found that the shorter rest periods tend to give better purification.

Digesters should be heated and insulated and piping should be so arranged that sludge can be recirculated from the bottom to the top. Centrifugal pumps are not in general satisfactory for handling heavy sludge and their use should be discouraged. Providing a direct connection of the water supply to the heat equipment of the digester is a dangerous practice and providing a cross-connection should never be followed. The control valves should always be outside of a digester tank in order that they can be operated and repaired with ease. The piping should be so arranged that the supernatant liquor from the digester can go to the sludge beds, secondary treatment, primary sedimentation tank, sludge lagoon (if one is provided), or to a sludge concentration tank. Equipment companies should be required to put their equipment in operation after the plant is completed and to instruct the operator in its proper operation. If the treatment plant, together with all the appurtenances and the mechanical equipment, are conducive to sanitary and efficient operation, the man in charge will generally rise to the occasion and take pride in doing a good job.

Rolf Eliassen

CONTROLLING POLLUTION OF OYSTER-GROWING WATERS OF CHESAPEAKE BAY

By George L. Hall

Civil Engineering, 11, 715 (Dec., 1941)

The prevalence of typhoid fever in Chicago, New York, Washington, and several other cities during the winter of 1924–25 led to detailed investigations on the part of the U. S. Public Health Service to determine the cause of the unusually high typhoid rate. The consumption of raw oysters grown in polluted waters was cited as the cause. Wide publicity was given to the cause of this wave of typhoid, and as a result the general public avoided oysters for a time. The oyster business in the eastern part of the country was practically at a stand still as there was very little demand for the product. Great financial losses were suffered by the oyster packers, and many of them were compelled to close. With the co-operation of the U. S. Public Health Service, closer control over the oyster waters in the United States was undertaken jointly by the several oyster-producing states and the federal government for the purpose of assuring the output of a safe product under proper sanitary control both in the growing areas and in the methods of handling and transportation. Following the typhoid outbreak and its effect on the Maryland oyster industry, a special appropriation was made available to the State Department of Health for extending its studies of the oyster-bearing waters and the shucking and packing houses in this state. The Department Bureau of Sanitary Engineering was assigned the duty of sampling all oyster bars and the overlying waters and making the necessary surveys of adjacent land areas for the purpose of determining the areas from which the taking of shell fish should be prohibited. This work was started early in 1925.

In Chesapeake Bay and tributaries there are approximately 273,885 acres of oyster-bearing waters. Since the beginning of the control program in 1925, over 25,500 samples of oysters and overlying waters have been collected and examined in the bacteriological laboratory of the State Department of Health. The analytical findings are reviewed critically in relation to the data from the sanitary surveys. The results have caused restrictions to be placed on twelve locations in the bay and tributaries, within the limits of each of which the taking of oysters is prohibited, because of present or possible future sewage pollution. The combined area of the restricted waters is only about 0.6 per cent of the total oyster-producing area in Chesapeake Bay. Of all the sewage from cities and towns now discharging into tide water, 96.7 per cent now receive some form of treatment. There are still several towns emptying untreated sewage into the upper reaches of some of the tidewater streams but they are located anywhere from 12 to 35 miles away from the nearest oyster bar. Where sewage treatment plant effluents discharge into tidewater in proximity to oyster areas, chlorination of the effluent is required by the State Department of Health. As an additional safeguard to the ultimate shell fish consumer, the taking of oysters from waters in the vicinity of sewer outlets is prohibited. As the result of this work, the oyster industry in Chesapeake Bay is now producing an oyster crop amounting to 2½ million dollars each year, and the consumers can be assured of a safe product.

Rolf Eliassen

CONSTRUCTING A TREATMENT PLANT FOR INDUSTRIAL WASTES

By J. W. Greenleaf, Jr.

Civil Engineering, 11, 483–486 (Aug., 1941)

Standard Brands, Inc., have recently erected a plant for treating 300,000 gallons per day of concentrated wastes from a yeast and malt factory at Pekin, Illinois. The plant involves plain sedimentation in covered settling tanks for four hours, after which the entire flow is pumped to one of six digestion tanks, each 50 ft. in diameter with a side depth of 22 ft. Each tank is provided with an oil-sealed gas dome which also serves as a vacuum and pressure-relief valve. The gas is being burned in two waste gas burners but it is planned to utilize this gas either in an engine for power or in boilers for the generation of heat in the future. Calculations based on pilot plant operations show a heat value for the gas of about $2,000 a year, based on coal at $1.50 a ton. After digestion for about 10 days, the liquid is mixed with approximately 5 m.g.d. of relatively clean condenser water and discharged into the Illinois River.

ROLF ELIASSEN

EMERGENCY SEWAGE TREATMENT

BY EDWARD A. SMITH

Engineering News-Record, 127, 174 (July 31, 1941)

Camp Croft in Spartenburg, S. C., was confronted with the necessity of providing occupancy for troops 45 days before the scheduled date of completion. This created an emergency situation with regard to sewage disposal. The small creek into which the effluent from the camp sewer was to be discharged had a winter flow providing a dilution of only one to one. Provisions were made for digging an emergency sedimentation tank in a level section of the creek valley adjacent to the sewage pumping plant. Provision was made for two hours sedimentation followed by 20 minutes in a chlorine contact basin. Calcium hypochlorite was added to provide a slight chlorine residual in the effluent. The average dosing was equivalent to 8 p.p.m. Analyses indicated that the B.O.D. was reduced from 215 to 115 p.p.m. by sedimentation and chlorination and the suspended solids reduced from 472 to 165 p.p.m. in the same process. The tanks were in use for less than two months so that digestion did not take place. After the main sewage plant had been constructed, the earth basins were abandoned and the sludge was dosed with 1,000 lb. of lime and back filled with earth. This provided an excellent method of handling the sewage for a population of from 2,000 to 8,000 over a brief period in the winter.

ROLF ELIASSEN

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

SECRETARIES OF MEMBER ASSOCIATIONS

Any individual desiring to affiliate with the Federation as an Active Member, may do so by joining one of the Member Associations listed below. Write to the Secretary for particulars.

Association	*Secretary*	*Address*
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California Sewage Works Association	Jack H. Kimball	Orange County Health Dept., Box 355, Santa Ana, California
Central States Sewage Works Association	E. J. Beatty	c/o State Board of Health, Madison, Wisconsin
Dakota Water and Sewage Works Conference		
(North Dakota Section)	H. G. Hanson	c/o State Dept. of Health, Bismarck, North Dakota
(South Dakota Section)	E. R. Mathews (Acting)	Div. of San. Eng., c/o State Board of Health, Pierre, South Dakota
Federal Sewage Research Association	R. S. Smith	U. S. P. H. S., East Third and Kilgour Sts., Cincinnati, Ohio
Florida Sewage Works Association	S. W. Wells	c/o Florida State Board of Health, Jacksonville, Florida
Georgia Water and Sewage Association	T. T. Gunter	c/o Water Filtration Plant, Atlanta, Georgia
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Michigan Sewage Works Association	R. J. Smith	Mich. Dept. of Health, State Office Bldg., Lansing, Michigan
Missouri Water and Sewerage Conference	Warren Kramer	State Board of Health, 200 Monroe St., Jefferson City, Missouri
New England Sewage Works Association	LeRoy W. Van Kleeck	State Dept. of Health, State Office Bldg., Hartford, Connecticut

New Jersey Sewage Conference	R. C. Smith	29 High Street, Glen Ridge, New Jersey
New York State Sewage Works Association	A. S. Bedell	c/o State Dept. of Health, Albany, New York
North Carolina Sewage Works Association	R. S. Phillips	P. O. Box 1170, Durham, North Carolina
Ohio Sewage Works Conference Group	W. D. Sheets	240 Binns Boulevard, Columbus, Ohio
Oklahoma Water and Sewage Conference	H. J. Darcey	State Dept. of Health, Oklahoma City, Oklahoma
Pacific Northwest Sewage Works Association	Fred Merryfield	Civil Engineering Dept., Oregon State College, Corvallis, Oregon
Pennsylvania Sewage Works Association	Bernard S. Bush	Penna. Dept. of Health, Kirby Health Center, Wilkes-Barre, Pennsylvania
Rocky Mount Sewage Works Association	Dana E. Kepner	1921 Blake Street, Denver, Colorado
Sewage Division—Texas Section, S. W. W. A.	V. M. Ehlers	State Dept. of Health, Austin, Texas
The Canadian Institute on Sewage and Sanitation	A. E. Berry	Sanitary Engineering Div., Ontario Dept. of Health, Toronto, Ontario, Canada
Sanitary Engineering Division of Argentine Society of Engineers	Carlos Santos Rossell	Centro Argentino de Ingenieros, Cerrito, 1250, Buenos Aires, South America
The Institute of Sewage Purification—England	J. H. Garner	28 Aberford Road, Wakefield, Yorks., England
The Institution of Sanitary Engineers—England	Mrs. E. M. Kerry (Acting)	118 Victoria Street, Westminster, S.W. 1, England

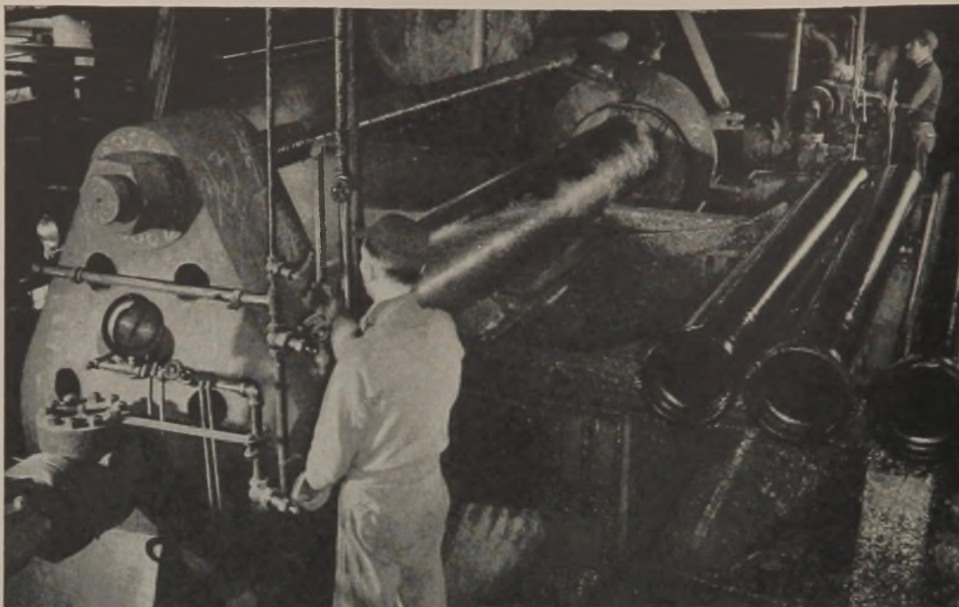
LOCAL ASSOCIATION MEETINGS IN 1942

Association	*Place*	*Date*
Arizona Sewage Works Association		
California Sewage Works Association		
Central States Sewage Works Association	Minneapolis, Minn.	June 18–19
North Dakota Sewage Works Conference	Williston, N. D.	Oct., 1942
South Dakota Sewage Works Conference		
Federal Sewage Research Association		
Florida Sewage Works Association		
Georgia Water and Sewage Association		
Iowa Wastes Disposal Association		
Kansas Water and Sewage Works Association		
Maryland-Delaware Water and Sewerage Association		
Michigan Sewage Works Association		
Missouri Water and Sewerage Conference		
New England Sewage Works Association		
New Jersey Sewage Conference		
New York State Sewage Works Association	New York, N. Y. (Hotel McAlpin)	Jan. 23–24
North Carolina Sewage Works Association		
Ohio Sewage Works Conference		
Oklahoma Water and Sewage Conference	Stillwater, Okla.	Jan. 19–23
Pacific Northwest Sewage Works Association	Corvallis, Ore.	May 7–9
Pennsylvania Sewage Works Association	State College, Pa.	Aug. 24–26
Rocky Mount Sewage Works Association		
Sewage Division, Texas Section, S. W. W. A.		
Canadian Institute on Sewage and Sanitation		

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Third Annual Meeting, Cleveland, Ohio,

Oct. 15–17



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