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SEWAGE WORKS JOURNAL

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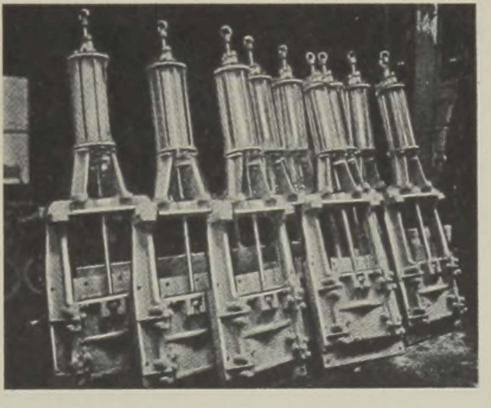

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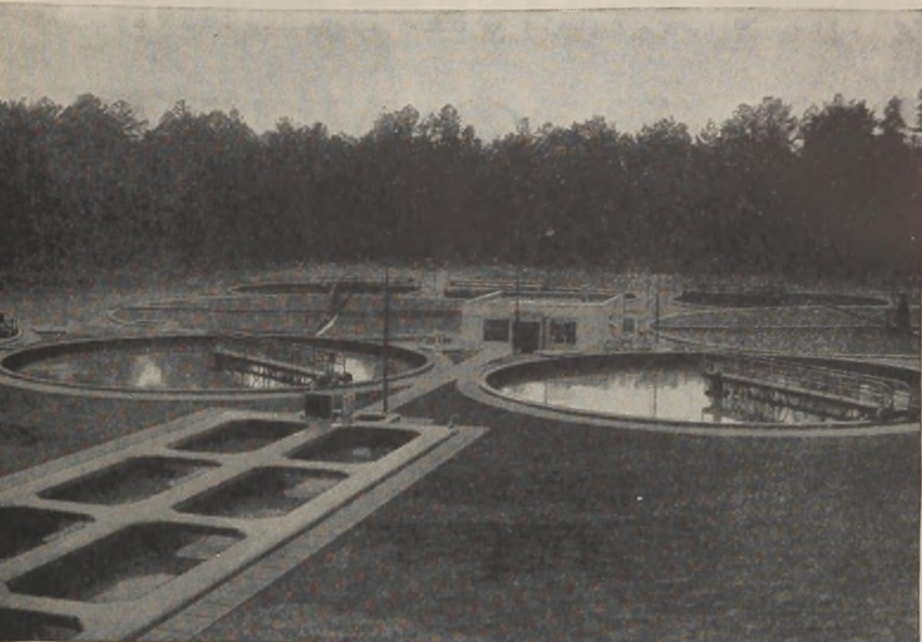

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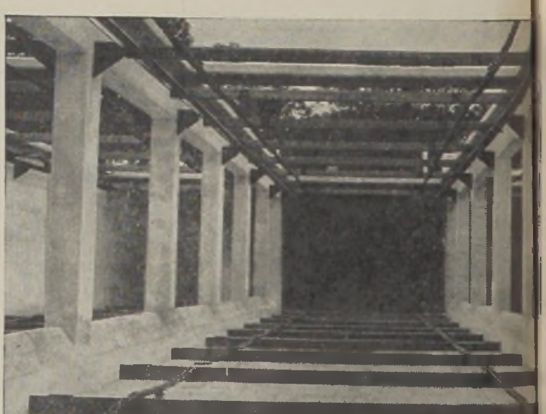

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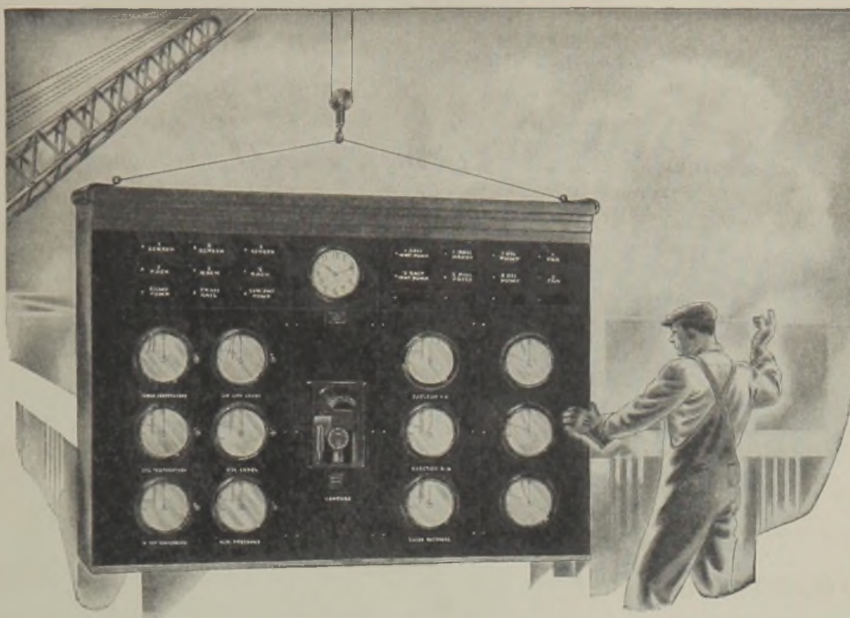

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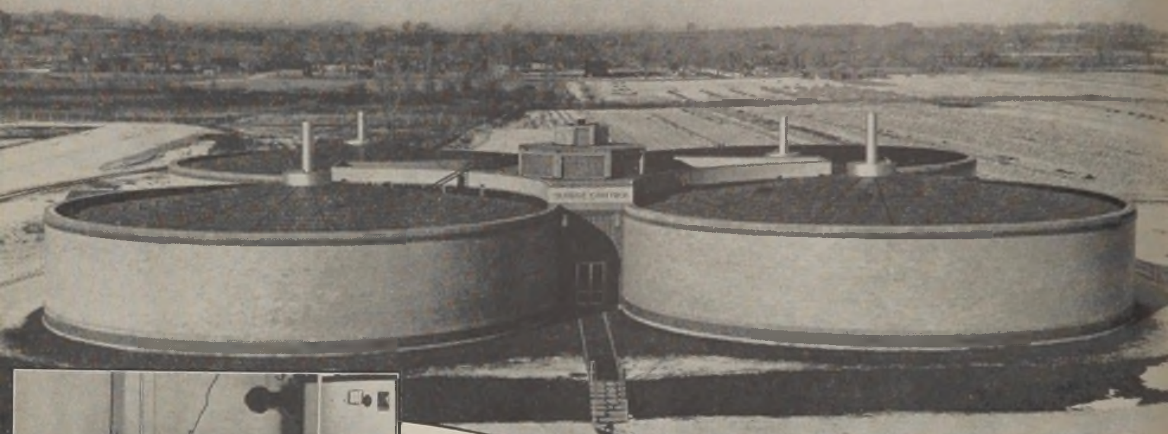

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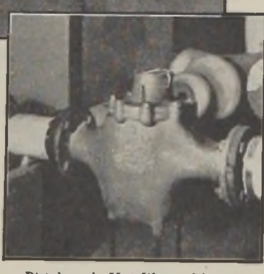

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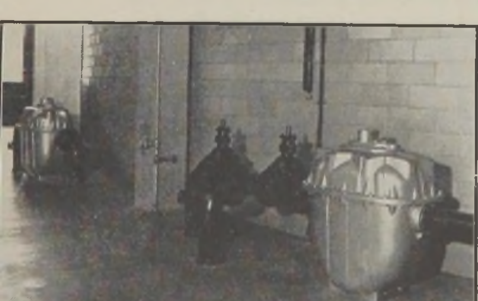

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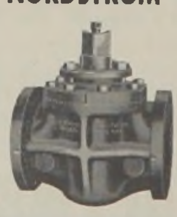

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Sewage Research

DETERMINATION OF DISSOLVED OXYGEN BY THE DROPPING MERCURY ELECTRODE *

By Robert S. Ingols

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The essential role of oxygen in sewage treatment processes and in streams recovering from pollution is well recognized, inasmuch as the most readily available source of oxygen for the organisms present in the sewage or stream is dissolved oxygen. It is highly desirable to obtain a method for determining dissolved oxygen which is accurate, rapid and continuous. The Winkler method and its modifications are sufficiently accurate for most determinations at the sewage plant and in stream survey work, but they are not rapid nor continuous. In determining dissolved oxygen by the Winkler method on a large number of samples from a stream or sewage works, either much time must be allowed for adding reagents to each sample or the accuracy gained by taking the samples to a central point must be sacrificed. For continuous dissolved oxygen studies no method has been available which could be used without an operator present for each sample. The need for knowing the dissolved oxygen in activated sludge plant operation was brought out forcibly by Edwards (2) when he stated that the control of the dissolved oxygen in aeration tanks is one of the best aids to operation and that control of the air supply is the most important variable under supervision of the operator. One of the best means of controlling the discharge of sewage or industrial wastes into a stream would be a knowledge of the dissolved oxygen in the receiving stream at several points for 24 hours for seven days in a week. Study of the dropping mercury electrode indicates that this instrument provides a rapid, accurate, method which can be developed as an indicating device or modified to obtain a continuous record of the dissolved oxygen content.

The measurement of oxygen consumption by activated sludge and sewage under various conditions has been used by Bloodgood (1) Kessler and Nichols (7) for control of activated sludge plant operation. However, this method takes several hours to obtain results and although it may prevent the development of serious conditions, it does not tell the conditions in the aeration tanks at all times. The maintenance of the sludge in a proper condition would be much better served by a knowledge of the dissolved oxygen in the aeration tanks at all times. Such tests are made in most activated sludge plants at more or less frequent intervals.

* Journal Series Paper, New Jersey Agricultural Experiment Station, Rutgers University, Department of Water and Sewage Research.

In research upon the activated sludge process in the laboratory, where it is necessary to study small volumes for several days, it has been impossible to determine the dissolved oxygen at frequent intervals because the quantity of material used for the Winkler test is large and the volume of the material under study is reduced to the extent of interfering with the maintenance of controlled conditions. The dropping mercury electrode fulfills all of these requirements, because the sample can be studied continuously for dissolved oxygen without losing liquor for analysis.

Apparatus

Petering and Daniels (13) published an article on the determination of dissolved oxygen by means of the dropping mercury electrode, with applications in biology, indicating that dissolved oxygen can be measured with simple laboratory equipment directly upon a sample which can be kept for subsequent analyses. The simple apparatus such as that shown in Fig. 1 does not record the dissolved oxygen continuously, but the galvanometer may be read at any time and the dissolved oxygen known at any given time. The galvanometer can be changed for recording. The apparatus was assembled from standard equipment. In the circuit shown an automobile storage battery (*A*) is connected in series with a resistance box (*B*) and a student potentiometer (*C*). The secondary circuit from the potentiometer is connected in series with a sensitive galvanometer (*D*) (10^{-8} amperes), and for purposes of calibrating the potentiometer with a Weston standard cell (*G*). When the potentiometer has been calibrated the negative pole is connected to the dropping mercury electrode reservoir (*K*), the other pole to the calomel half cell (*H*). The mercury reservoir is connected by rubber tubing to the capillary (*J*). Both the capillary and the calomel half-cell are mounted on a rubber stopper which fits the 2-liter Erlenmeyer flask (*M*). This mounting of both electrodes on the rubber stopper permits the ready transfer of the electrodes from one flask to another, for practically simultaneous measurement of several similar solutions. The flask shown has been fitted with a side arm (*N*) to permit the entrance of a tube from the gas supply to the aerator ball (*L*) which is independent of the electrodes. The galvanometer is protected with an Ayrton shunt (*F*) and the oscillations of the galvanometer caused by the changes in the current flow, due to the formation of the mercury drops, are damped by a 4000 microfarad condenser (*E*) as recommended by Lingane and Kerlinger (9). The calomel half-cell (*H*) is made from a long glass tube with a side arm fitted with a sintered glass plug (*I*) for electrical diffusion, yet backed with a saturated potassium chloride agar plug to retard the rate of diffusion. Instead of the calomel half-cell the dropping mercury electrode is generally used with a pool of mercury at the bottom of the flask as the second electrode, but this increases both the surface of mercury exposed to the test solution and the quantity of mercury to be handled and cleaned. The calomel half-cell was recommended by Lingane and Laitimen (10).

Theory

For a complete theoretical discussion, see Kolthoff and Lingane (8), Muller (11) and Heyrovsky (3), the originator of this method of analysis. Petering and Daniels (13) give a good discussion of the theory of the use of the dropping mercury electrode in the determination of dissolved oxygen. The dropping mercury electrode can be used to determine substances which can be reduced or oxidized. In order to determine those substances which can be reduced the mercury drop is made negative, while to determine the substances which must be oxidized, the drop is made positive. In the study of oxidimetry, it is well recognized

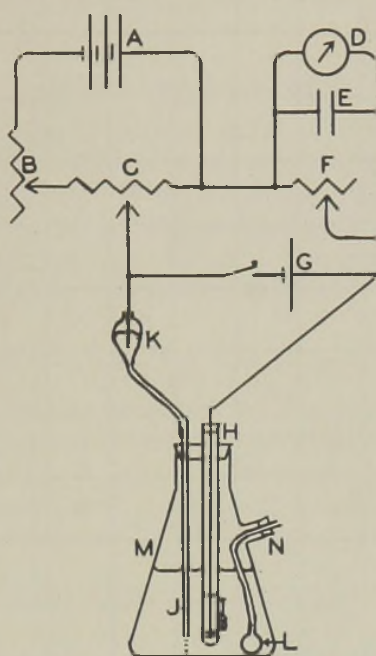

Fig. 1.—Schematic circuit and cell for the dropping mercury electrode determination of dissolved oxygen.

that the potential at which one material can be oxidized or reduced is lower or higher than that potential at which another substance can be oxidized or reduced. The same principle is used in the dropping mercury electrode system of analysis in which the voltage applied at the mercury drop yields the necessary potential to bring about the chemical reaction which might have been produced by chemicals of the correct potential. The voltage at which the chemical reaction takes place is similar to that for the chemical reaction and is characteristic of a substance. As the voltage applied to the drop approaches that necessary for the chemical reaction at the surface of the mercury the quantity of current flow between the electrodes increases as shown by the galvanometer. Maintenance of constant temperature in the test solution and of a constant mercury dropping rate are important for accurate results.

Once the mercury drop leaves the capillary, the chemical reaction on that drop ceases (at least in so far as the galvanometer readings are concerned) and the surface of the newly forming drop becomes the reactive surface. The increase in current flow at a particular voltage is used to indicate the presence of the particular element or ion or substance in a solution which is similar to a known solution containing that element, ion or substance (similar in respect to pH and other materials whose characteristic voltage may be near that of the substance under test). The increase in the quantity of current flow is limited by the concentration of

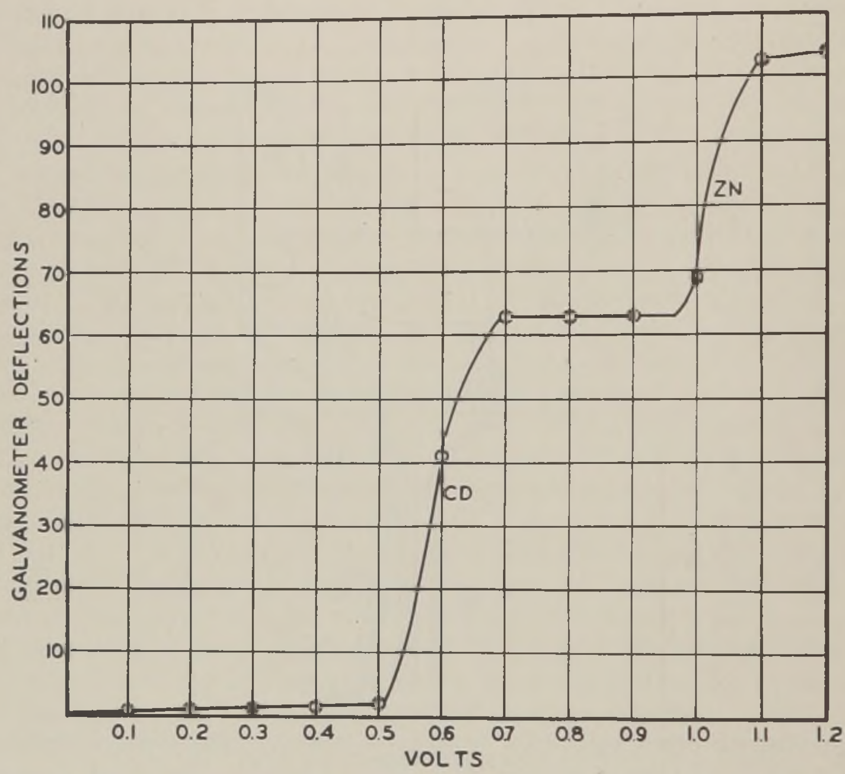

FIG. 2.—Current voltage curve obtained with a solution of cadmium and zinc sulfates.

the ion, element or substance under test and the current does not continue to increase as the characteristic voltage is exceeded. Apparatus has been developed to vary the voltage at a regular rate and simultaneously measure and record the quantity of current increases. This may be done manually with the apparatus shown in Fig. 1 and the points plotted as shown in Fig. 2. This method of analysis does not lend itself to completely unknown solutions. The characteristic potentials of each of the substances present must be known and an increase in current for a given increase in concentration of the substance must be determined.

Although the circuit appears to be similar to that used for conductivity measurements there are several differences: (1) the voltage applied to the dropping mercury electrode is very much less than the voltage applied to the conductivity electrodes, (2) with this dropping electrode there is a continually changing area of contact with the solution whereas conductivity electrodes are constant in area, (3) the dropping mercury electrode is charged continuously with one pole of electricity while a high frequency alternating current is used for conductivity, (4) better values with the dropping mercury electrode for low concentrations of substances of low potential are obtained in the presence of a comparatively high concentration of a salt containing an ion of a higher potential (solution having high conductance). Since there is the similarity of this circuit to that by which conductivity is measured, a study of the effect of a change in the conductivity of sewage will be made and correlated with the effect upon the determination of dissolved oxygen in the sewage.

Method of Operation

In using the dropping mercury electrode the electrodes are submerged in the solution and the mercury level adjusted so that one drop forms in two to six seconds. With no voltage applied across the electrodes, the zero reading of the galvanometer is obtained. This is important, because the 4000 microfarad condenser gives off a current which is quite sensitive to temperature changes and may be large in

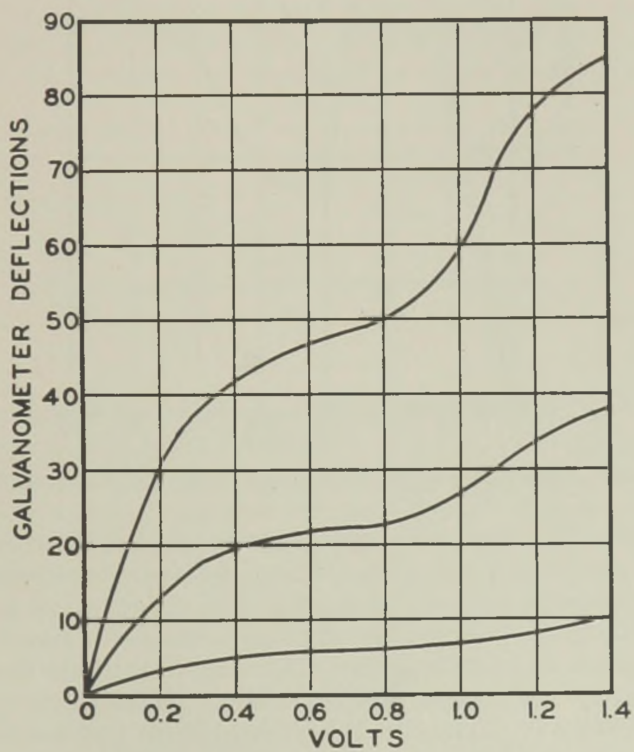

Fig. 3.—Current voltage curves of the same sample of sewage at different dissolved oxygen values.

proportion to the total current when concentrations are low. In the determination of all reducible substances except dissolved oxygen, this gas must be removed from the solution by bubbling with either hydrogen or nitrogen. For the actual analysis, a low voltage is applied across the electrodes and the voltage increased in small steps while the increase in current is noted as recorded by the galvanometer with each increase in

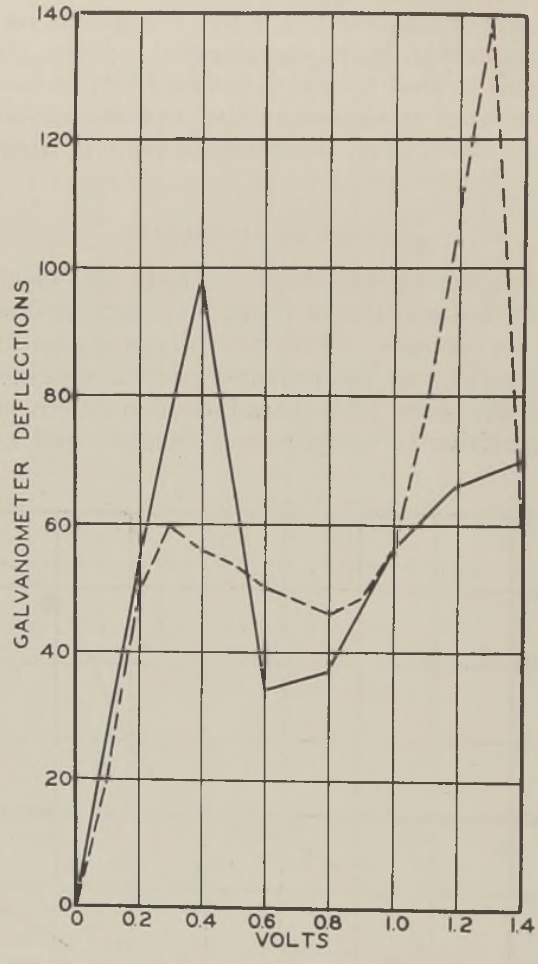

FIG. 4.—Current voltage curves of the same sample of tap water saturated with oxygen.

voltage made. The data obtained are plotted on a characteristic current voltage curve such as in Fig. 2, where the increases in current shown are due to cadmium and zinc sulfates. The amounts of cadmium and zinc must be determined from the current increases for known concentrations of cadmium and zinc sulfates. If interested only in the determination of the cadmium present in the solution the entire current voltage curve is unnecessary. The current reading at 0.5 volt can be taken and then the reading at 0.7 volt; the difference represents the increase due to the cadmium. This short cut is possible only when all of the substances present are known. If another substance had been present in the solution with a characteristic voltage very close to that for zinc, one of the substances should be removed before the other could be determined with the electrode. This is true of oxygen.

The shorter method of determining the current flow at only two voltages is suggested by Petering and Daniels (13) for the determination of the dissolved oxygen. They recommend that one should take a current flow reading at 0.1 volt and 1 volt and correlate the difference in the readings with the dissolved oxygen determined for two points on a curve by the Winkler method.

With these recommendations in mind, current-voltage curves on sewage and tap-water were made as shown in Figs. 3 and 4. The curves for the same sample of tap-water coincide at 1 volt only so that no other voltage on these irregular curves could be correlated with the dissolved oxygen. The irregularities in the tap-water curves are called "maxima" and are due to the lack of large molecules in the solution. Sewage contains large molecules in solution and so smooth current voltage curves are obtained (Fig. 3). Peptone was added to the solution for Fig. 2 to give the smooth curve of this figure.

The regularity of the curves for sewage suggested that some correlation between the differences in the current readings at 0.1 volt and 1.0 volt was possible. Sewage was aerated for several minutes and the two necessary readings at 0.1 volt and 1.0 volt obtained and the dissolved oxygen value determined. After a short interval each of these operations was repeated. The results were as follows:

	Galvanometer Reading at Volts		D.O., P.p.m.
	0.1	1.0	
1st sample	81	153	5.0
2nd sample	71	154	5.0

The galvanometer readings at 0.1 volt are not constant enough, even with sewage, to give good correlation with the dissolved oxygen.

From this preliminary work and a study of the references cited, it was considered that changes in dissolved oxygen could be followed with the potentiometer set at 1.0 volt and all readings taken at this voltage only. Therefore, several types of sewage samples were obtained and the typical data shown in Table I prepared for each sample. The curves of the correlations between the dissolved oxygen (Winkler) and the galvanometer readings for three samples are shown in Fig. 5. It can be seen that the slope varies slightly for different samples. These differences in slope may be due to the compounds in the sewages which interfere with the Winkler determination or with the dropping mercury electrode. When a new method for dissolved oxygen must be correlated

TABLE I.—*Correlations Between Current Flow and Dissolved Oxygen (Winkler)*

Galvanometer Readings			Corrected Galvanometer Deflections	Winkler Dissolved Oxygen, P.p.m.
Condenser	(Shunt)	With Sample		
−39	1 x	−21	0	0.0
−39	10 x	−37	0	0.0
−37	1 x	+6	25	0.35
−36	1 x	+37	55	0.75
−36	10 x	−2	320	4.3

against the Winkler method which may be, at best, 0.1 to 0.2 p.p.m. from the actual dissolved oxygen value, the good agreement in each sample and the close approach of different samples is considered an excellent recommendation for the new technique.

For the determinations shown in Table I and Fig. 5 the potentiometer was set at 1.0 volt and left for the balance of the determinations.

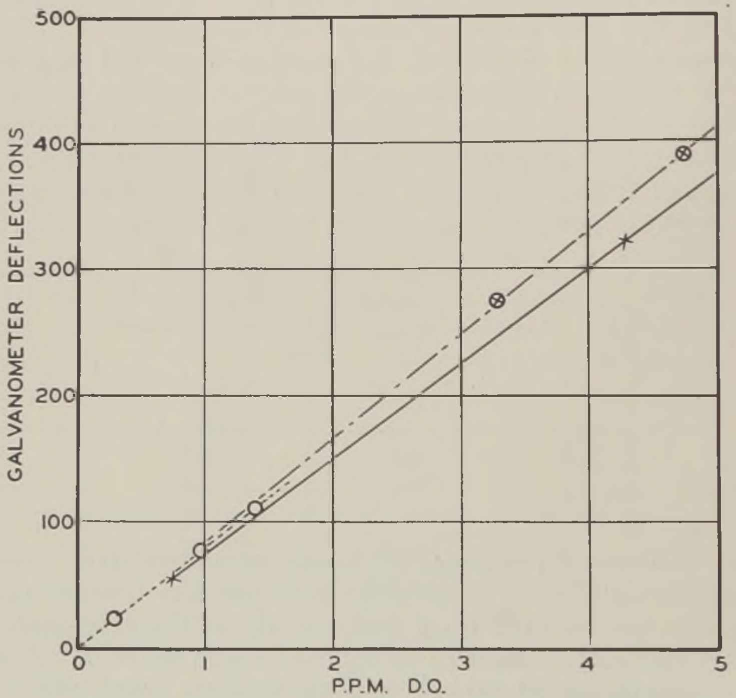

FIG. 5.—Correlation of current flow with dissolved oxygen in three samples of sewage.

The secondary circuit was broken and the reading of the galvanometer with the condensers taken; this was repeated at each reading because of the fluctuations in this current. The sewage was agitated for several minutes with nitrogen until a reading was obtained twice, as near the condenser reading as possible, and was considered as constant throughout the rest of the experiment. The sample was then aerated and a galvanometer reading taken and the dissolved oxygen determined chemically (Winkler). These operations were repeated several times, and the results plotted. One point determines the slope of the curve but several points were plotted as a check upon the method.

It is frequently desirable to determine the dissolved oxygen variations continuously in a sample of sewage or in activated sludge-sewage mixture. For this purpose the instrument is set with the potentiometer at 1.0 volt, and the fluctuations in the galvanometer readings noted against the curve for dissolved oxygen. The curve for the dissolved oxygen is determined either by taking two dissolved oxygen values by the Winkler method in the range studied, or by finding the zero point by bubbling with nitrogen and then finding the slope of the curve with one chemical analysis for dissolved oxygen. Especially in activated sludge plant operation, where continuous dissolved oxygen values are desired, it is generally important to know whether the dissolved oxygen is rising or falling and what range is present and not whether the dissolved oxygen is exactly 0.8 p.p.m. or 0.9 p.p.m. or exactly 4.5 or 4.6 p.p.m. Thus, for plant operation some of the refinements of technique necessary in the laboratory for exact work may be eliminated, while good accuracy can be obtained in the laboratory with the dropping mercury electrode.

Possible Sources of Error

To study the effect of a change in conductance (change in salt concentration), the dissolved oxygen was determined after the addition of sodium chloride to a sample of sewage. To the sample of sewage used in Table I, 1500 p.p.m. sodium chloride was added. A dissolved oxygen of 0.35 p.p.m. was obtained by the Winkler method while the galvanometer reading indicated a dissolved oxygen of 0.48 p.p.m. when read from the curve in Fig. 5 or an error of 0.13 p.p.m. This error can be eliminated if a galvanometer reading is obtained in the absence of dissolved oxygen to give the zero reading. This may not be possible if a continuous reading is recorded in an aeration tank or stream. However, the magnitude of the addition of chlorides was much higher than that which is normally expected in a sewage treated by the activated sludge process and still the error is less than the accuracy generally desired. For batch experiments there need be no error.

Nitrate and nitrite ions which are formed by activated sludge cause no error in the dissolved oxygen determination for they are reduced at voltages more negative (14, 15) than the one volt used for determining dissolved oxygen. Further, there must be an absence of oxygen for the determination of the nitrate and nitrite ions. Zinc and arsenic cause increases in current at one volt which is the same as that used for oxygen, as shown for zinc in Fig. 2. Neither zinc nor arsenic are likely to be found in appreciable quantities in sewage, but if small amounts were discharged into the sewer they do not remain as free ions but react with the soaps or other organic material in the sewage before contacting the electrode. However, if zinc is present and the dissolved oxygen determined or varied, the galvanometer is set at one volt and with all of the oxygen removed the galvanometer reading is used as the zero point. The slope of the curve is obtained by correlating a Winkler dissolved oxygen determination with one other galvanometer reading. A curve for dissolved oxygen in the zinc and cadmium sulfate solution was made and the slope of the curve could be superimposed upon the lowest curve of Fig. 5.

In the correlation of galvanometer deflections and Winkler dissolved oxygen values in septic sewage the values fall upon a straight line when the septic sewage has been aerated vigorously before the measurements were made, but not otherwise. The author believes that the interference of septic sewage with the Winkler method is the cause of the poor correlation. The error may amount to 0.7 p.p.m. dissolved oxygen in 5 p.p.m. while the error is less with lower dissolved oxygen concentrations.

A Correlation of Dissolved Oxygen and Nitrifcation

One of the important processes which frequently accompanies sewage purification by activated sludge or trickling filter treatment is nitrification of some of the ammonia. Usually a long or intense aeration period is needed to produce nitrification in activated sludge plants and many designers and operators do not aim to produce nitrates in normal activated sludge plant operation. With high-rate trickling filters nitrates will not form readily, but the conventional filters are good nitrifiyng devices. Several years ago Myerhof (12) showed that nitrification is retarded with a reduction in the oxygen tension in the air above the liquor of a nitrifying culture. Reduction in the oxygen tension was produced both with evacuation and dilution of the air with nitrogen. If this reduction in the rate of nitrification could be obtained by controlling the dissolved oxygen concentration with active agitation of the liquor it would tend to explain why nitrates fail to form near the inlet end of an activated sludge aeration tank and help in understanding why nitrates and nitrites may fail to form in the upper layers of a trickling filter.

Using a highly nitrifying sludge to study the effect of different D.O. levels upon the rate of nitrification, the activated sludge was aerated for a week while making daily changes of supernatant, with mineral water and urea as the source of ammonia. No organic carbonaceous material was used. At the end of a week the supernatant was withdrawn and more mineral water and urea, to the extent of 40 p.p.m. nitrogen, added. One portion of the sludge was agitated with air while a second portion was agitated with gas containing 5 per cent oxygen. The dropping mercury electrode cell was placed in the sludge, agitated with the reduced oxygen gas. The dissolved oxygen results at hourly intervals are recorded in Table II, but readings were taken very frequently until equilibrium was reached and then checked at intervals.

The dissolved oxygen values for the sludge agitated with air were taken hourly because the dissolved oxygen level was so high that slight variations would have less effect upon nitrification. Nitrites and nitrates were determined hourly from both portions. The results, given in Table II, show a marked retardation in the nitrite and nitrate production with the lower dissolved oxygen value of 0.7 p.p.m. The lower rates of nitrite production during the first hour, especially with the lower dissolved oxygen value, were apparently due to the addition of urea to the sludge once a day, for a sludge dosed three times a day and kept at

TABLE II.—*Effect of Different Dissolved Oxygen Values Upon the Rate of Nitrification*

Time of Aeration, Hours	Control			Low Dissolved Oxygen		
	D.O. Present, P.p.m.	Produced Hourly		D.O. Present, P.p.m.	Produced Hourly	
		Nitrites, P.p.m.	Nitrates, P.p.m.		Nitrites, P.p.m.	Nitrates, P.p.m.
1st	4.3	2.8	2.0	0.6	0.2	0.0
2nd	5.0	5.5	5.0	0.7	1.5	1.0
3rd	4.0	4.0	3.0	0.7	2.1	2.0
4th	3.0	6.5	5.0	0.6	3.0	2.0
5th	3.8	7.0	6.0	0.7	4.0	3.0
Totals		25.8	21.0		10.8	8.0

the low dissolved oxygen concentration did not show initial retardation, even after a period of three hours quiescence in the absence of dissolved oxygen.

In an effort to show how low the dissolved oxygen must be before nitrification is blocked entirely, results (Table III) indicate that the dissolved oxygen was maintained at 0.2 p.p.m. for three hours. At this low dissolved oxygen value, the formation of nitrates was blocked while some nitrites were formed. The low nitrite production during the second hour for the control was due to a lack of available ammonia during that period.

TABLE III.—*Effect of Low Dissolved Oxygen Upon the Rate of Nitrification*

Time, Hours	Control			Low Dissolved Oxygen		
	D.O. Present, P.p.m.	Produced Hourly		D.O. Present, P.p.m.	Produced Hourly	
		Nitrites, P.p.m.	Nitrates, P.p.m.		Nitrites, P.p.m.	Nitrates, P.p.m.
1st	4.5	3.0	2.0	0.2	1.5	0.0
2nd	4.5	2.0	2.0	0.2	1.5	0.0
3rd	5.0	4.5	3.0	0.2	1.0	0.0
Totals		9.5	7.0		4.0	0.0

Discussion

That the dropping mercury electrode method of determining dissolved oxygen is well suited for indicating continuously the dissolved oxygen has been demonstrated by effect of dissolved oxygen upon nitrification. With lower dissolved oxygen concentration, the rate of supply of air was adjusted to bring the galvanometer reading to the desired value. Using a galvanometer with an indicating scale, an operator could perform other duties and watch the dissolved oxygen concentration by merely glancing at the scale. This simple, less expensive instrument may be adapted for plant operation and be of real value to the plant operator in controlling the dissolved oxygen concentration at a desired level, while recording instruments will be desirable at larger plants.

The results with nitrification show that low dissolved oxygen concentrations definitely retard both nitrite and nitrate formation, and that as the oxygen concentration gets low enough the nitrate formation is blocked while nitrite formation may continue. The actual dissolved oxygen level that supports nitrification is probably higher for plant requirements, because in this experiment no actual sewage constituents were present and only very little carbon oxidation was in progress. The carbon oxidation factor was eliminated purposefully to simplify the interpretation of the results; therefore these results point definitely to the effect of low dissolved oxygen upon the nitrification process.

Kehr (6) has shown that sewage retards the rate of oxygen diffusion (reaeration) into stream water. When sewage is mixed with activated sludge or dosed on a trickling filter, solids of various types collect at the floc or slime surfaces. As these materials collect it would seem reasonable that the diffusion rate of oxygen into the floc would be retarded. Any retardation in the rate of oxygen diffusion becomes more important when the oxygen demand for carbonaceous oxidation is high. The importance given to these factors is based on the concept that the nitrifying organisms are a definite part of the slime or floc and must obtain their oxygen in competition with other organisms present in the slime or floc. Because the competition for the oxygen is great in the upper layers of the trickling filter and during the early stages in the aeration tank, nitrification takes place more rapidly in the lower layers of the trickling filter and in later stages of the aeration tank. With many earlier laboratory experiments upon activated sludge the dissolved oxygen concentration has been maintained so high that the oxygen diffusion rate was high enough to permit the nitrifying organisms to compete successfully for the oxygen. Nitrification and carbonaceous oxidation proceeded simultaneously (5), indicating (4) that there is real antagonism between the processes for dissolved oxygen, but with enough dissolved oxygen both processes proceed simultaneously.

Summary and Conclusions

The importance of knowing the dissolved oxygen concentration in stream pollution studies and sewage plant operation is discussed. A new method for determining the dissolved oxygen in these waters both rapidly, accurately, and continuously, uses the dropping mercury electrode. Calibration of the new equipment indicates that the instrument for determining the dissolved oxygen is suited for indicating or recording continuously the dissolved oxygen concentration in activated sludge aeration tanks or in streams.

The effect of different dissolved oxygen concentrations upon the rates of nitrification was determined by the use of the dropping mercury electrode. It was shown that low dissolved oxygen concentrations have a definite retarding effect upon nitrification.

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CHEMICAL COAGULATION OF SEWAGE

XIV. PROTEINS AS AN AID TO CHEMICAL TREATMENT *

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In the course of experimental work on the chemical treatment of sewage an investigation of the effect of natural and added colloidal sols was made on the efficiency and speed of coagulation, clarification, floc formation and settling. The addition of protein sols in quantities as low as 2 p.p.m. produced marked changes in coagulation. The light, slowly settling floc produced by normal chemical treatment was transformed into heavy ball-like particles, averaging about a quarter of an inch in diameter, which settled despite the agitation during flocculation. The amount of coagulant necessary to produce complete clarification was reduced by the addition to sewage of the protein sol. An illustration of the effect of small quantities of proteins on coagulation is shown in Table I.

A search of the literature revealed that some work was published on the effect of protein sols on the settling of pigments (1) and of silica suspensions (2) and for clarifying wines and beers (3), (4). The only pertinent information pertaining to sewage coagulation and the use of proteins found was a patent covering the A. B. C. process (5), used in England during the nineteenth century. The coagulant used in this process was a mixture of alum, various inert materials and some dried blood. The quantity of blood actually added to the sewage in this process amounted to less than 0.5 p.p.m. The amount of protein actually applied was too small to produce results distinguishable from those obtained with a coagulant alone.

Certain substances in solution in sewage have been shown to exert an influence toward keeping fine sewage solids dispersed. It is logical to assume, therefore, that others might act in an opposite manner, rendering them more easily coagulated. This appears to be a particularly plausible theory when the observations of the effect of protein sols on sewage coagulation are considered.

Experimental

(1) *Dosage of Protein.*—Preliminary tests had demonstrated that small dosages of proteins could improve coagulation considerably. The optimum dosage was not determined, neither was the question of the probable variation of protein requirements of different sewages answered.

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Table I.—*Effect of Small Quantities of Proteins on Chemical Coagulation*

P.p.m. Iron ($FeCl_3$)	P.p.m. Albumen 0	P.p.m. Albumen 2
	P.p.m. Turbidity Remaining	
30	71	44
35	56	16
40	38	10
45	18	<5
Character of Floc	Small. Settles slowly	Floc very large. Settles rapidly

P.p.m. Iron ($FeCl_3$)	P.p.m. Gelatin 0	P.p.m. Gelatin 5
	P.p.m. Turbidity Remaining	
10	105	50
15	91	21
20	70	8
25	40	<5
30	<5	—
Character of Floc	Small. Settles slowly	Large, ball-like floc. Settles rapidly

P.p.m. Aluminum (Alum)	P.p.m. Gelatin 0	P.p.m. Gelatin 5
	Turbidity Remaining	
4	98	85
6	73	41
8	48	<5
10	21	—
12	<5	—
Character of Floc	Fine. Settles slowly	Large, granular. Settles rapidly

In order to determine these factors a number of six-liter portions of a sewage were treated with graduated dosages of gelatin solution, containing 10 milligrams of protein per ml. The six-liter portions were divided into one-liter aliquots, placed in battery jars and treated with graduated dosages of ferric chloride. The samples were flocculated thirty minutes and settled for one hour. The quantity of ferric chloride necessary to produce an effluent having a turbidity of less than 20 p.p.m. was taken as the demand dosage. This experiment was repeated with three other sewage samples from different sources (Table II).

The dosage of protein required to produce optimum coagulation varied somewhat with different sewage (from 4 to 10 p.p.m.). All the samples treated responded well when 5 p.p.m. of gelatin was used resulting in the formation of a rapid settling floc and reducing the coagulation demand. Increased dosages of gelatin, within reasonable limits, did not alter the results obtained. Greatly excessive dosages were detrimental; they raised the coagulant demand and produced an enormous amorphous floc which did not settle well.

TABLE II.—*Dosage of Gelatin Necessary to Improve Coagulation*

Sewage 1			Sewage 2		
P.p.m. Gelatin Added	Coagulant Demand, P.p.m. Iron ($FeCl_3$)	Character of Floc Formed	P.p.m. Gelatin Added	Coagulant Demand, P.p.m. Iron ($FeCl_3$)	Character of Floc Formed
0	35	Fine floc	0	20	Fine floc
1	35	Fine floc	1	20	Fine floc
3	25	Large floc	2	17	Granular floc
5	20	Large ball floc	3	17	Granular floc
8	20	Large ball floc	4	15	Large ball floc
10	20	Large ball floc	5	15	Large ball floc
20	20	Large ball floc	6	15	Large ball floc
30	20	Large ball floc	7	15	Large ball floc
40	20	Large ball floc	8	15	Large ball floc
50	25	Very large floc	9	15	Large ball floc
120	50	Very large floc	10	15	Large ball floc
Sewage 3			Sewage 4		
0	25	Fine floc	0	15	Fine floc
4	15	Large ball floc	5	12	Large, granular
8	15	Large ball floc	10	10	Large ball floc
20	20	Large ball floc	25	10	Large ball floc
30	—	Large ball floc	50	15	Large, amorphous floc
40	—	—	75	20	Large, amorphous floc
50	25	Very large, amorphous floc	100	30	Large mass
100	—	—	—	—	—

(2) *Protein—coagulant Compounds.*—The difficulties attending the dissolving, storing and feeding of proteins in sewage plant operation are obvious. To overcome these objections a more convenient means of applying the protein was sought.

The literature on protein compounds was consulted and numerous references pertaining to the formation of proteinates with the chlorides of heavy metals were found. It appears that the protein molecule attaches itself to the chloride ion forming a type of hydrochloride binding with the metal ion. The extent of the reaction depends upon the concentration of the metal chloride salt thus allowing the formation of innumerable compounds rather than a single one in which the reacting ingredients are present in stochiometric proportion.

Preliminary trials showed that ferric and aluminum chlorides readily combined with various proteins forming stable compounds which were readily soluble in water or solutions of the metallic chloride salts.

Numerous tests were made using different methods of mixing the ingredients. The best procedure was to hydrate the gelatin with a minimum amount of hot water and then to add anhydrous ferric chloride, kneading the resulting mass to a stiff paste. The paste, if it did not contain too much ferric chloride, air dried to a hard brittle film if spread out. Drying could be accelerated by raising the temperature to 50° C. Drying at higher temperatures was attended by some decomposition.

In order to determine what ratio of protein and coagulant would produce the best compound, ferric chloride and gelatin were combined in the ratios of 1:2, 2:3, 1:1, 3:2, 2:5, 5:2, 3:1, 4:1 and 5:1. These compounds were tested for solubility in water, the presence of free ferric chloride, and the ability to dry to a stable non-hygryoscopic form. Their relative merit for treating sewage was also determined by floc-

TABLE III.—*Characteristics of Compounds Formed by Combination of Various Ferric Chloride Ratios*

Ratio $FeCl_3$ to Gelatin	Solubility of Compound in Water	Presence of Free $FeCl_3$	Ability to Form Dry, Stable Material	Clarifying Properties	Floc Forming Properties
1 : 2	Dissolves slowly leaving residue	None	Good	Fair	Large, amorphous
2 : 3	Dissolves slowly	None	Good	Fair	Large, amorphous
1 : 1	Dissolves fairly rapidly	None	Good	Good	Large, rapid settling
3 : 2	Dissolves very rapidly	None	Very good	Good	Large, ball-like floc
2 : 1	Dissolves very rapidly	None	Very good	Good	Large, ball-like floc
5 : 2	Dissolves very rapidly	None	Good	Good	Large, ball-like floc
3 : 1	Dissolves very rapidly	Trace	Fair	Good	Large, ball-like floc
4 : 1	Dissolves very rapidly	Present	Poor	Good	Large, ball-like floc
5 : 1	Dissolves very rapidly	Present	Poor	Good	Large, ball-like floc

culation trials in which their clarifying ability and floc-forming properties were recorded. Some of the results are shown in Table III.

The ratios low in ferric chloride in proportion to gelatin (1:2, 2:3 and 1:1) were undesirable on account of their solubility characteristics and relative inferior clarifying power. The floc formed by these compounds was large but bulky and did not settle well. Preparations formed with the ratios of ferric chloride to gelatin of 3:2, 2:1, and 5:2 had all of the desirable qualities, dissolving readily, forming stable dry compounds and yielding excellent coagulation results. When preparations were made in which the ferric chloride exceeded three or more times the weight of gelatin, the final product, although a good coagulant, contained free ferric chloride and was hygroscopic.

On the basis of these findings the ratios in the range of from 3:2 to 5:2 were chosen for use in this work. The 3:2 ratio was generally the one used for preparation of the coagulant. It was given the name of "ferrigel" for convenience.

(3) *Method of Application of Ferrigel for Coagulation of Sewage.*—The use of ferrigel (2:3 ratio) as such yielded a protein dosage in relation to the coagulant which was too high to be economical. With this compound as such two parts of gelatin would be added for every part of iron. By dissolving the ferrigel in a solution of ferric chloride a ratio of the constituents in accordance with the requirements for coagulation could be obtained.

The average sewage appears to have an iron demand of about 15 p.p.m. when ferrigel is applied, and 5 p.p.m. of gelatin will produce the desired effect on coagulation. A solution containing 5 parts of gelatin to 15 parts of iron (or 45 parts of ferric chloride) seems best for most purposes. In practice sufficient ferrigel can be dissolved in a ferric chloride solution of known strength to give this final ratio for feeding purposes. The final ratio of this solution would be 9 parts of ferric chloride to 1 of gelatin.

The solution made for laboratory coagulation tests contained 45 mgms. of ferric chloride and 5 mgm. of gelatin per ml. Using this solution sufficient gelatin was always present to produce the desired results when enough iron was added to clarify the sewage, while overdoses of the protein were avoided. The following figures show the dosages of gelatin obtained at fixed iron dosages when this solution was used:

P.p.m. Iron	P.p.m. Gelatin
5	1.7
10	3.3
15	5.0
20	6.7
25	8.3
30	10.0

(4) *Relative Effectiveness of Compounds Made with Different Proteins.*—Compounds of ferric chloride of the proteins zein, gluten, casein, peptone and gelatin were prepared using the 3:2 ratio. The zein, gluten and casein did not combine as readily or form as readily soluble compounds as the other proteins. Some residue remained on preparation of the zein and gluten compounds. This was probably due to the impure variety of protein used.

Amounts of the compounds were dissolved in ferric chloride solution of such strength that final solutions contained 15 mgm. of iron and 5 mgm. of protein per ml.

Liter portions of sewage were treated with dosages of the solution of each compound varying from 0 to 40 p.pm. in the usual manner. Clarification produced in all cases was measured by the turbidity remaining.

The clarification curve obtained with each compound is plotted in Fig. 1. It was noted that in all cases where the demand dosage of the

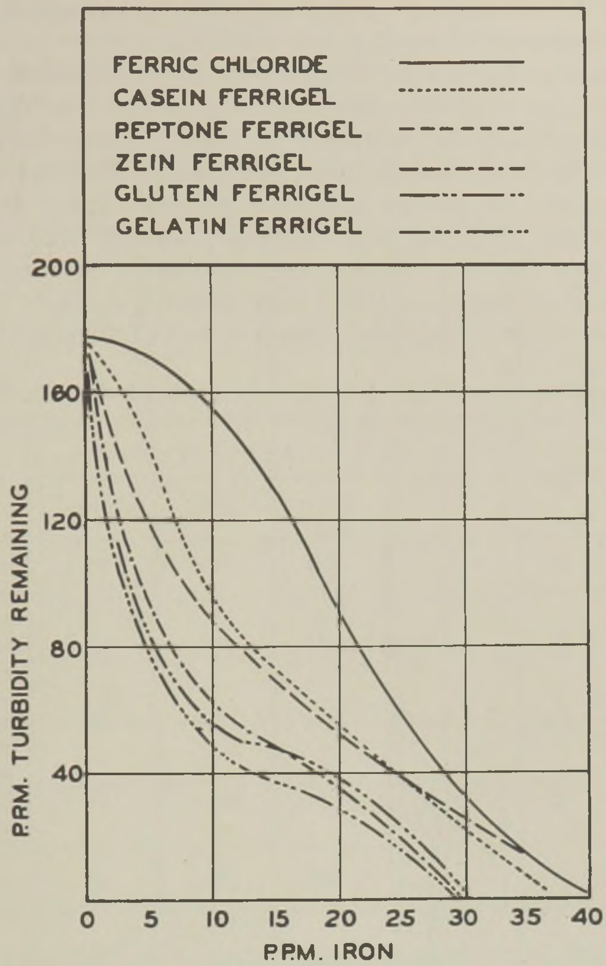

FIG. 1.—Clarification curves of ferric chloride—protein compounds.

protein coagulants were used, large ball-like floc formation occurred. As for clarification obtained all the compounds were superior to ferric chloride per unit weight of iron employed. The order of clarifying effectiveness of the compounds was gelatin, gluten, zein, peptone and casein. Gelatin was only slightly better than the gluten and zein compounds. All three were definitely better than the peptone and casein. The gelatin, however, had added advantages from the standpoint of preparation of compounds and character of the final product which designated it as the best with which to work.

In order to determine if impure forms of gelatin were as effective as pure forms a sample of iso-electric gelatin, free of ash and impurities, was obtained. From this material a 3:2 ratio ferrigel was prepared. Similar preparations were made from Difco gelatin, non-edible gelatin and glue. The treating solution was prepared from each of these preparations and coagulation tests on sewage made. Turbidity, oxygen consumed, and B.O.D. tests were made on the clarified samples and observations on the character of the floc formed included.

A tabulation of the results (Table IV) showed that very similar results were obtained with all four types of gelatin. Clarification, B.O.D. and O.C. removal and the character of the floc formed was similar in every case. It will be noted that the same sewage treated with a higher dosage of iron and no gelatin produced no appreciably greater B.O.D. or O.C. reduction. Because non-edible gelatin and glue were as effective as the purer forms of gelatin and sufficiently low in cost to allow their use in sewage treatment they were selected as basic materials for the preparation of the compound, referred to as "ferrigel."

TABLE IV.—*Effect of Type of Gelatin on Clarification and Floc Formation*

Gelatin Used	P.p.m. Fe	P.p.m. Gelatin	Analysis of Effluent			Character of Floc
			P.p.m. Turb.	P.p.m. B.O.D.	P.p.m. O.C.	
Ash Free	15	5	<20	68.0	40	Large, ball-like. Settles during stirring
Difco	15	5	<20	67.5	42	Large, ball-like. Settles during stirring
Non-Edible	15	5	<20	66.0	39	Large, ball-like. Settles during stirring
Glue	15	5	<20	68.0	44	Large, ball-like. Settles during stirring
None	25	0	<20	65.0	42	Small, slow settling

pH.—The effect of pH on the coagulation of sewage with ferrigel was studied over a range of from pH 2.9 to 9.4. Samples of sewage were pre-adjusted with lime in the higher pH range and sulfuric acid in the lower range to specific values. Treatment with ferrigel was applied in such a manner that the gelatin dosage was constant at 5 p.p.m. and the ferric chloride dosages varied from 4 to 14 p.p.m. of iron. Turbidity remaining in the effluents was measured and the results plotted in Fig. 2. Observations on type of floc formed were also made. Below pH 8.5 the characteristic rapidly settling ball-like floc formed. At pH 8.5 and above, this phenomenon did not take place; the floc formed was fine and settled slowly.

Lowering the pH appeared to produce good clarification and large floc formation with lower dosages of ferrigel than were necessary at the normal pH of sewage. To lower the pH values of the sewage, carbon dioxide was passed through two large samples of a sewage sufficiently long to reduce the pH from 7.5 to 6.5 and to 5.5. A third sample was retained without treatment as a control. Coagulation tests were made with each sample to determine how much ferric chloride in the form of ferrigel was required to produce complete clarification. The dosage of gelatin applied was kept constant at 5 p.p.m. This experiment was repeated with three different sewages. As the results in all cases were similar, the average results are presented in Fig. 3. A reduction of 25 per cent in the amount of iron was evident when the pH was lowered to 6.5, and 35 per cent when lowered to 5.5 with carbon dioxide.

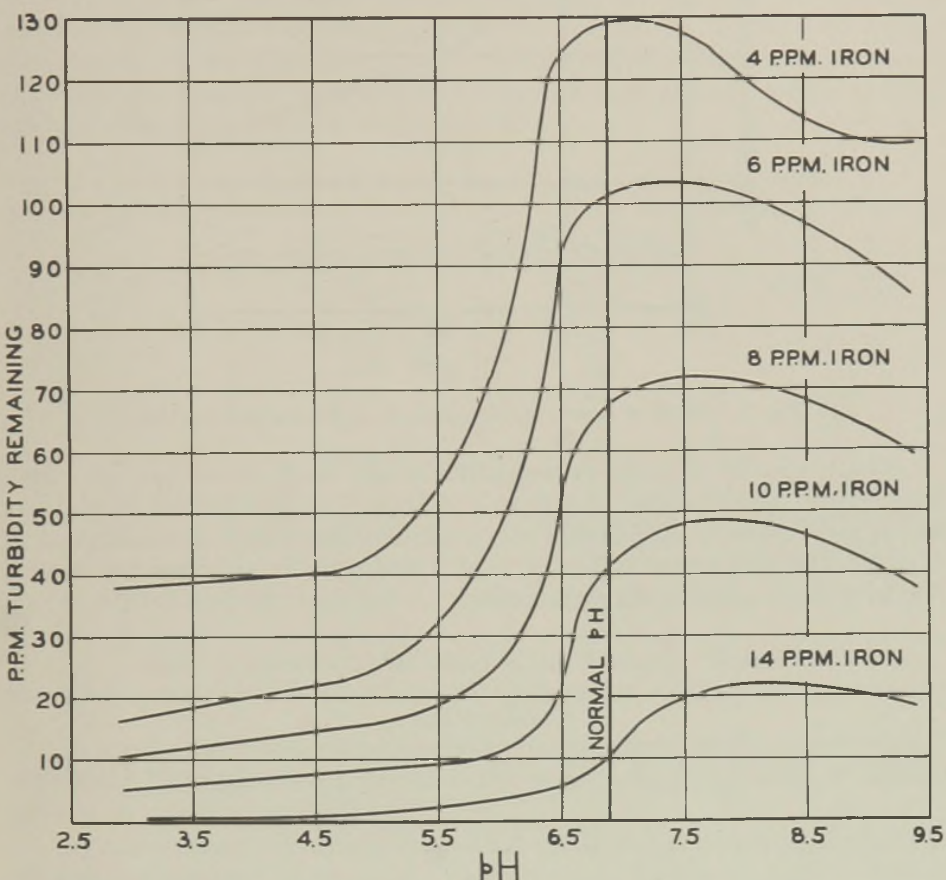

Fig. 2.—Effect of pH on clarification with ferrigel.

Mixing and Flocculation.—Experiments were conducted to determine the best method of application of ferrigel in respect to mixing and flocculation. Mixing was accomplished in three ways, namely, flash mixing (by violent vertical agitation with a flat plate), rapid mixing (paddles on stirring machine running at 100 r.p.m.) and slow mixing (paddles running at flocculation speed—30 r.p.m.). Samples of sewage were aliquoted and treated with corresponding dosages of ferrigel employing the three methods of mixing. All samples were flocculated in the usual manner following mixing. Clarification was measured by turbidity in the supernatant after settling and the character of the floc formed was observed. Table V is a tabulation of the results obtained.

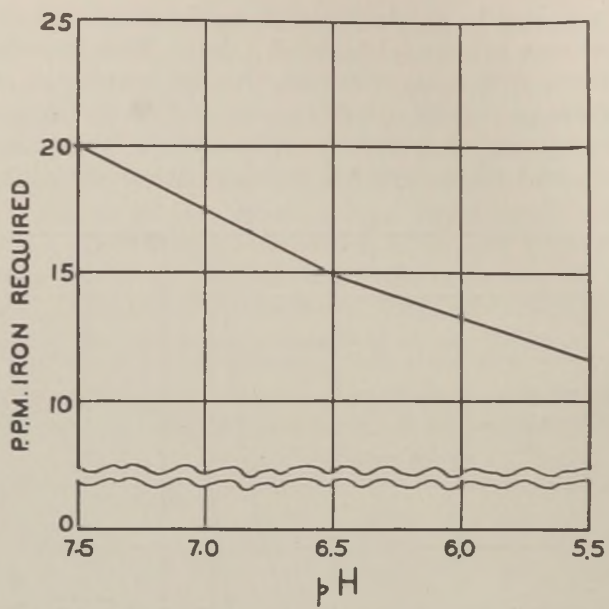

FIG. 3.—Effect of carbon dioxide aeration on the ferrigel demand.

These results show in general that while flash mixing yields somewhat better clarification at equivalent iron dosages, the large ball-like floc is not formed. Rapid mix gives a heavy floc which is not always of the ball-like character. This type of mixing yields at times a granular floc with good settling characteristics. A floc with the best settling prop-

TABLE V.—*Type of Mixing as Applied to the Application of Ferrigel*

Sewage Sample	Type of Mixing	P.p.m. Iron (Ferrigel)					Character of Floc Formed
		10	15	20	25	30	
		P.p.m. Turbidity Remaining					
1	Flash	78	38	<20	—	—	Fine, slow settling
	Rapid	80	38	<20	—	—	Large, granular, rapid settling
	Slow	91	57	<20	—	—	Large, ball-like, rapid settling
2	Flash	—	—	92	48	24	Fine, slow settling
	Rapid	—	—	93	53	20	Small, granular floc
	Slow	—	—	108	59	10	Large, ball-like, rapid settling
3	Flash	148	105	58	29	5	Fine, slow settling
	Rapid	159	105	62	24	5	Large, ball-like, rapid settling
	Slow	173	121	80	38	20	Large, ball-like, rapid settling

erties is obtained by mixing at flocculation speed of 30 r.p.m. The results obtained with this method of mixing are preferred despite the fact that a slightly higher dosage of iron is required to produce the same degree of clarification.

Bacteria Removal.—The bacterial removing properties of ferrigel were compared with ferric chloride. Separate aliquots of a sewage sample were treated with sufficient dosages of ferrigel and of ferric chloride to produce complete clarification. Total 20° C. bacteria counts and *E. coli* counts were made on the clarified supernatants after settling. This experiment was repeated with four different sewage samples. The counts obtained are given in Table VI.

Table VI.—*Bacterial Removal by Ferrigel as Compared to Ferric Chloride*

Sewage Sample	Raw Sewage	$FeCl_3$ Treated Sewage	Ferrigel Treated Sewage
Total 20° Bact., thousands per ml.			
1	1890	540	210
2	6300	290	100
3	2100	500	600
4	—	340	400
E. Coli, thousands per ml.			
1	150	15	5
2	140	14	8
3	440	51	61
4	—	45	45

Despite some variations observed, it appears that there were few if any consistent differences in the removal of total bacteria or *E. coli* obtained by the two coagulants.

In connection with the removal of bacteria the chlorine demand of clarified effluents is of interest. In order to determine if any difference in chlorine demand existed in effluents obtained by the use of ferrigel as compared to ferric chloride, the samples of clarified sewage from the experiment on bacterial removal were tested for their chlorine demand by the standard method. In Table VII the comparative figures are

Table VII.—*Chlorine Demand of Ferrigel Effluents Compared to Ferric Chloride Effluents*

Sewage	Ferrigel Treatment		Chlorine Demand Effluent	Ferric Chloride Treatment	Chlorine Demand Effluent
	Iron	Gelatin			
1	15	7.5	5.0	25	5.0
2	20	4.0	4.5	30	4.5
3	20	5.0	4.0	30	4.0

given. All samples showed that no difference existed in the chlorine demand of the effluents produced by ferrigel and those produced with ferric chloride.

Effect of Floc.—It was thought possible that because of its peculiar characteristics the floc produced on coagulation of sewage with ferrigel might have clarifying power if added to untreated sewage. Sixteen one-liter portions of a sewage were treated with sufficient ferrigel (15 p.p.m. iron 5 p.p.m. gelatin) to clarify the sewage completely. The sludge from each was separated from the clear liquor. Four samples were set aside, four other pairs of samples were combined and the remaining combined in four sets each containing the sludge from three liters of sewage. This was done in such a manner that the floc was not broken up appreciably. Four sets of four one-liter samples of the same sewage were then poured into jars. To one set of four, no sludge was

Table VIII.—*Effect of Return Sludge on Ferrigel Treatment*

Conc. of Return Sludge on Sewage Solids Basis	P.p.m. Iron (Ferrigel)			
	0	5	10	15
	P.p.m. Turbidity Remaining			
0	106	72	40	<20
1 : 1	110	69	50	<20
2 : 1	110	75	57	<20
3 : 1	Floc Breaks Up			

added. To the second set the sludge obtained from one-liter portions of sewage was added, to the third set the sludge from two liters of sewage and to the fourth set the sludge from three liters of sewage. This gave four sets of one-liter samples, each containing one sample with no return sludge, one with an equal weight of solids as return sludge, another with twice the weight as return and the last, three times the weight of sludge present in the samples without return sludge. One set was flocculated without additional coagulant, the second with 5 p.p.m. of iron as ferrigel, the third with 10 p.p.m. and the fourth with 15 p.p.m. After flocculation for 30 minutes and settling for one hour the turbidity of the supernatants of all samples was determined. The results obtained are given in Table VIII.

In the light of these results it is evident that return ferrigel sludge does not aid clarification. It was also observed that nothing was gained from the standpoint of floc formation or settling by any of the concentrations of return sludge used.

Dewatering.—Inspection of the ball-like floc after settling revealed that the floc particles seemed to retain their identity after settling and not to merge wholly into a homogeneous sludge, indicating that the sludge should dewater readily and perhaps without conditioning chemicals.

After preliminary trials, 30 gallons of sewage was poured into a steel drum and treated with sufficient ferrigel to produce complete clarification. The sludge was allowed to settle and then drawn off into two-liter cylinders in which it was allowed to compact for 24 hours. At the end of this period the clear supernatant was siphoned off and 100 ml. samples used for Buchner funnel dewatering tests. The time of dewatering was determined without the use of conditioning chemical and with graduated dosages of ferric chloride. This experiment was repeated with three different sewages. The data obtained is tabulated in Table IX.

It is apparent that the sludge obtained from sewage coagulated with ferrigel can be dewatered by vacuum filtration without the addition of conditioning chemical. Small quantities of ferric chloride (0.4 to 1.0

TABLE IX.—*Dewatering Properties of Ferrigel Sludge, Plainfield Sewage Treated with Ferrigel* (20 p.p.m. Fe, 8 p.p.m. Gelatin)

	Per Cent $FeCl_3$ for Conditioning					
	0	0.44	0.59	0.73	0.88	1.0
Minutes to Obtain Dry Cake	10	4	3	3	2	1
Character of Filtrate	Clear	Clear	Clear	Clear	Clear	Clear
Per Cent Moisture in Cake	79	79	76	76	76	77

Freehold Sewage Treated with Ferrigel
(25 p.p.m. Fe, 10 p.p.m. Gelatin)

	Per Cent $FeCl_3$ for Conditioning					
	0	0.29	0.59	0.88	1.18	1.47
Minutes to Obtain Dry Cake	10	7	6	4	3	2
Character of Filtrate	Clear	Clear	Clear	Clear	Clear	Clear
Per Cent Moisture in Cake	76	—	—	72	—	71

Elizabeth Sewage Treated with Ferrigel
(20 p.p.m. Fe, 4 p.p.m. Gelatin)

	Per Cent $FeCl_3$ for Conditioning				
	0	0.19	0.38	0.77	.96
Minutes to Obtain Dry Cake	10	6	3	2	2
Character of Filtrate	Clear	Clear	Clear	Clear	Clear
Per Cent Moisture in Cake	74	75	77	76	76

per cent), however, greatly enhanced the filtration as indicated by the lowering of the filtration time from ten to as low as one minute.

As ferrigel was effective in producing a dewaterable sludge it was thought possible that it might be more effective for sludge dewatering than ferric chloride. To determine the relative effectiveness of the two, aliquots of a sample of fresh solids were treated with comparative

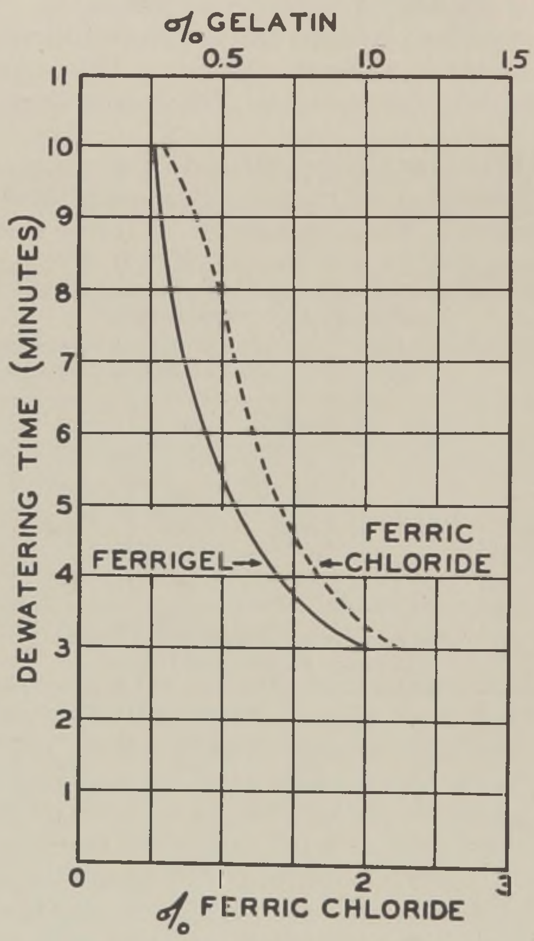

FIG. 4.—Ferrigel and ferric chloride compared for the dewatering of fresh solids.

dosages of the two chemicals. A ferrigel preparation containing two parts of ferric chloride to one of gelatin was used in these tests. The common Buchner funnel method of determining dewatering rate was employed. On completion of the test with the fresh solids sample the procedure was repeated with a ripe sludge sample.

For dewatering fresh solids ferrigel was only a slight improvement over ferric chloride as Fig. 4 shows. Ripe sludge, however, responded more markedly to ferrigel than to ferric chloride. As will be seen on inspection of Fig. 5 the amount of ferric chloride to give equivalent results was cut in half when ferrigel was used for conditioning.

Other Gels.—The coagulating and clarifying value of gelatin complexes prepared from other metallic salts was studied. Gels were prepared by combining in the ratio of two parts metal to one of gelatin. Cupric chloride, zinc chloride, aluminum chloride and ferric chloride

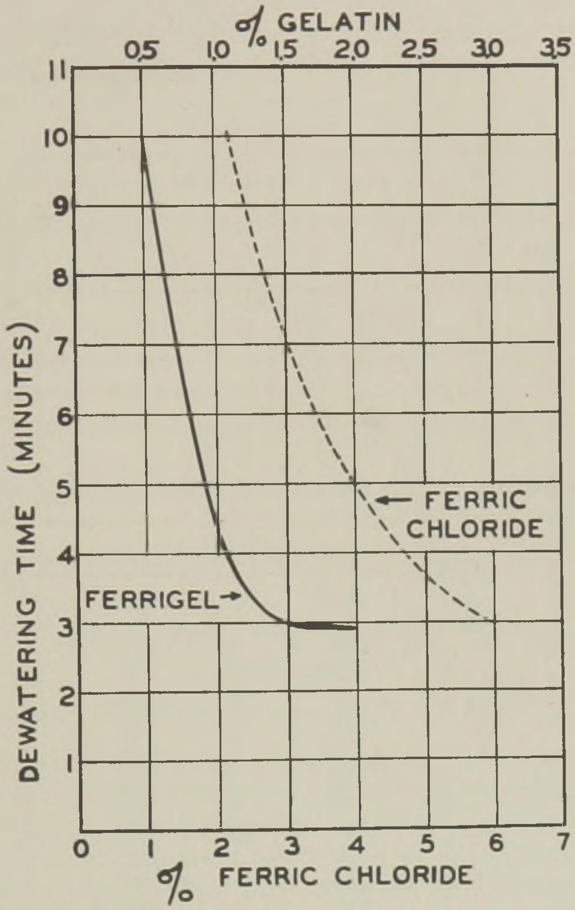

FIG. 5.—Ferrigel and ferric chloride compared for the dewatering of ripe sludge.

were used. Resulting compounds were dissolved in solutions of the metal salt used to make the compound to adjust the ratio of metal to gelatin to the proper range. The dosage of these compounds necessary to clarify sewage was determined, and the optimum amounts added to different samples of sewage. The results on two samples of sewage are shown in Table X.

Aluminum chloride-gelatin compound gave excellent results both from the standpoint of clarification and floc formation as compared to ferrigel. This compound may be of greater interest in the water field.

TABLE X.—*Effectiveness of Gelatin Compounds Pprepared with Different Metallic Salts*

Sewage 1

Compound	P.p.m. Metal	P.p.m. Gelatin	Clarification	Floc Formation
Ferrigel	15	7.5	Good	Large, rapid settling
Aluminum-gel	5	2.5	Excellent	Large, rapid settling
Copper-gel	35	17.5	Good	Large, rapid settling
Zinc-gel	Results poor at all dosages			

Sewage 2

Compound	P.p.m. Metal	P.p.m. Gelatin	Clarification	Floc Formation
Ferrigel	20	10	Good	Large, rapid settling
Aluminum-gel	5	2.5	Good	Large, rapid settling
Copper-gel	40	20	Good	Large, rapid settling
Zinc-gel	Results poor at all dosages			

TABLE XI.—*Reduction in Iron Demand Obtained by Ferrigel over Ferric Chloride*

Sewage	Coagulant Demand, P.p.m. Fe		P.p.m. Gelatin
	$FeCl_3$	Ferrigel	
Plainfield	35	30	10.0
"	30	25	8.5
"	25	20	6.8
"	30	20	6.8
"	25	15	5.0
"	25	15	5.0
Freehold	30	25	8.5
"	25	20	6.8
"	40	30	10.0
South River	25	20	6.8
" "	30	25	8.5
" "	30	25	8.5
" "	25	20	6.8
" "	20	15	5.0
New Brunswick	15	10	3.5
" "	25	15	5.0
" "	10	5	1.7
Sayreville	20	15	5.0
"	20	15	5.0
"	10	5	1.7
Highland Park	15	10	3.5
" "	20	15	5.0
Average	24	18	6.1

The cupric chloride-gelatin complex could also produce good results but excessive dosage was required. In neither case did the zinc compound appear to have any clarifying value.

Reduction of Iron.—Throughout this study numerous comparisons of ferrigel and ferric chloride were made. A group with varying coagulant demand requirements has been brought together and tabulated in Table XI. The average reduction in ferric chloride demand by ferrigel was 25 per cent when using an average gelatin dosage of 6.1 p.p.m. It will be noticed that the reduction in ferric chloride demand varied from 5 to 10 p.p.m., but was not necessarily the same for sewage from a particular plant.

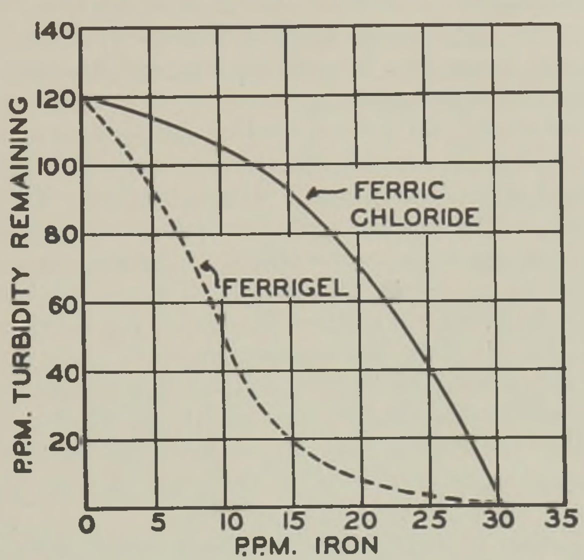

Fig. 6.—The clarification curve of ferrigel compared with that of ferric chloride.

The effect of graduated dosages of ferrigel and ferric chloride on clarification is of particular interest. As an example, five series of figures representing five different sewages were averaged and the averages plotted in Fig. 6. The difference in the type of curve produced by ferrigel is indicative of its superior clarifying qualities when dosages less than the demand are applied.

Discussion

The discovery that small dosages of proteins such as gelatin were effective in producing a heavy ball-like floc when sewage was treated with ferric chloride led to this investigation. It was shown that as little as 2 p.p.m. of protein not only changed the character of the floc but reduced the amount of ferric chloride necessary for partial and complete clarification. Larger dosages (5 to 10 p.p.m.) of protein were generally more effective than lower dosages, while quantities of from 10 to 40 p.p.m. were of no added value. Dosages over 40 p.p.m. were detrimental to clarification.

In search of an explanation for this phenomenon, the literature on colloidal chemistry was searched. It was found that in several investigations results were reported on the effect of proteins on the precipitation of pure colloidal sols with salt solutions (6) (7) (8). The general findings were that small additions of proteins such as gelatin, while not precipitating agents themselves, allowed precipitation of the colloids with much less salt than was necessary to produce the same result when no protein was added. The use of proteins for this purpose is referred to as ''sensitization'' and the action held to be the opposite of the phenomenon known as ''protection.'' The protective colloid protects the sol against coagulation and the sensitizing colloid makes it more readily susceptible to coagulation. The explanation of the sensitizing effect advanced is that the sensitizing agent attaches itself to the individual particles whereby it assumes coagulant response characteristics similar to those of the sensitizing agent.

In sewage treatment we are not dealing with a pure colloid dispersed in pure water, so that this explanation for the action of ferrigel in lowering the coagulant demand is open to some question. However, as substances dissolved in the sewage have the ability to increase the amount of coagulant necessary it is conceivable that the gelatin can act with the dispersed matter to overcome this effect. The results obtained appear to indicate that the gelatin sensitizes the dispersed substances in sewage to coagulation, but whether the mechanism is the same as that formulated for pure sols dispersed in distilled water has not been established.

It has been established that crystal growth is affected by gelatin (9). It is possible that the gelatin may affect the crystal lattice structure of the hydrous ferric oxide formed on coagulation thus accounting for the type of floc produced when gelatin is present.

The combination of proteins with heavy metal salts and acid has long been known and the nature of the combination has been subject of much debate. Without discussing the nature of the combination in detail, suffice it to say that compounds of metal salts and proteins having certain properties which made them suitable for our purpose were readily produced. These properties were dryness, ready solubility, stability, uniformity and applicability. The advantage gained by the use of a combination of a protein and metal is that only one chemical need be fed, while metal protein compounds are more readily soluble and more easily handled than the protein itself.

Zein, gluten, casein, albumen, peptone, and gelatin were the proteins used. Of these gelatin albumen and peptone yielded the best compounds. Commercial zein, gluten and casein left residues after treatment with ferric chloride, due to impurities present. The commercial albumen and peptone did not leave residues. Coagulation tests showed that all of these proteins produced a large heavy floc and lowered the amount of ferric chloride used for coagulation. This may be considered good evidence that the proteins in general and not the physical or chemical character of a particular protein is responsible for these responses.

The experiments also showed that gelatin was superior to the other proteins; it formed better compounds with ferric chloride, left no residue, and gave superior clarification results. The commercial materials needed for its preparation are available at low prices.

Since gelatin was the best protein for the purpose, experiments were conducted to determine whether or not the lower grades of gelatin were as effective as the high grade used in previous experiments, taking into consideration clarification, floc formation and B.O.D. and oxygen consumed (O.C.) reduction. To be of any practical value the cheap grades of gelatin would have to be used. Comparison of two very high grade gelatins (ash-free gelatin and Difco) with the two lowest (glue and non-edible gelatin) showed little if any difference. The non-edible gelatin was chosen as the best for our purpose on the basis of its low price and superiority in physical form over the glue. Also, it did not have an objectionable odor on reaction which was observed when glue-ferric chloride compounds were made.

The tests showed that the B.O.D. and O.C. reductions obtained by coagulating with ferrigel were as good as those obtainable with ferric chloride. Because the B.O.D. and O.C. values were as low as the effluents from ferric chloride treatment, it appears that the gelatin precipitates with the sludge and does not remain dissolved in the clear liquor.

The mixing experiments proved that for best results ferrigel should not be flash mixed or even rapid mixed on addition to the sewage. Mixing is best accomplished at flocculator speed. The presence of the gelatin seems to delay the action of the ferric chloride for sufficient time to allow good distribution through the sewage.

Ferrigel was as efficient as ferric chloride in removing bacteria which grow at 20° C. and *E. coli* from sewage. Counts on clarified effluents obtained by both methods of treatment were sufficiently close to warrant this conclusion. Bacterial removal by coagulating chemicals seems to be due more to their separation with the floc than by germicidal action of the coagulant.

The B.O.D. and O.C. and chlorine demand values were no higher in effluents from sewage clarified to the same degree with ferrigel than with ferric chloride. No difference in these values would be expected unless the gelatin remained in solution and was oxidized by bacteria, the acid $KMnO_4$, or by chlorine. Gelatin is oxidized by both bacteria and acid potassium permanganate as applied in the oxygen consumed test. Since the gelatin does not remain in solution but precipitates in the sludge it does not affect the B.O.D., O.C. or chlorine demand of the effluent. The results of experiments presented bear out this contention.

The absorption capacity of a ferrigel floc for dispersed sewage particles once completely formed is negligible. This was demonstrated by return sludge experiments. No concentration of return sludge, even when added with additional coagulant, aided clarification. When the total suspended solids concentration was raised four times above normal by addition of return sludge, mechanical flocculation dispersed the entire mass and clarification was poor. With ferrigel as with ferric chloride the greatest coagulation took place as the chemical reacted in the sewage.

Experiments demonstrated that the sludge produced by ferrigel coagulation could be dewatered without adding conditioning chemicals. Dewatering time was decreased, however, by treatment of the sludge with dosages of ferric chloride of less than one per cent. Even when no conditioning chemicals were added clear filtrates were obtained and cake moistures ran from 74 to 79 per cent. Addition of ferric chloride lowered the cake moisture on an average of about 3 per cent. The sludge obtained with ferrigel treatment settles and compacts very rapidly and it is conceivable that it could be removed from the settling chamber continuously and dewatered immediately and continuously.

Ferrigel used as conditioning agent did not produce very much better dewatering than did ferric chloride when used for conditioning fresh solids. The results obtained were almost identical per unit of ferric chloride. Ripe sludge, however, reacted more markedly. The dewatering time was cut in half when ferrigel was used at the same $FeCl_3$ concentration as the ferric chloride alone. When the gelatin cost was considered, however, no advantage was noted. It would be no more expensive to increase the ferric chloride sufficiently to halve the dewatering time than to use ferrigel. The interesting fact brought out by these tests is that ripe sludge containing a high concentration of bicarbonates dewatered well with ferrigel. The gelatin bound ferric chloride was evidently more available for coagulation than for reaction with the bicarbonates present in the sludge and thus more efficient in promoting dewatering.

A very efficient coagulant could be made by the combination of gelatin and aluminum chloride. This was to be expected as the factors affecting coagulation are not appreciably changed by the use of a protein. The trivalent cations iron and aluminum are good coagulants whether a sensitizing agent is present or not. The divalent cations are relatively poor coagulants as was demonstrated with the application of copper and zinc gelatin compounds. The formation of a large floc by the copper compound is indicative of the action of the gelatin on the dispersion.

The pH of the sewage treated affects the results obtained with all coagulants and consequently those obtained with ferrigel. On the acid side and up to a pH value of 8.5 the large rapid settling floc is readily formed but in the range above this value floc formation is poor and clarification at a given dosage not improved. The addition of lime is detrimental rather than an aid to this coagulant. Best results are obtained at pH values of 5.5 to 6.5. In this range floc formation is especially good and clarification remarkable. The fact that an iso-electric point of gelatin exists near this range might account for the results obtained.

Carbon dioxide application was found to be a good adjunct to coagulation with ferrigel as it readily brings the pH down in this range. It was found to be particularly effective with Monday sewages which are high in alkalinity.

The ability of ferrigel to allow an average of 25 per cent reduction in the amount of coagulant in 22 samples of sewage from six different sources indicates that such compounds are likely to be generally applicable and not peculiarly adaptable to one type of sewage. The sewages used included strictly fresh and stale domestic as well as domestic sewage containing trade wastes. During the experimental work with ferrigel no sample of sewage with a pH below 8.5 failed to respond to ferrigel coagulation.

The difference in the clarification curve obtained with ferrigel as compared to ferric chloride brings out some interesting points. Clarification of a much greater degree is obtained by partial dosages of ferrigel as compared to equivalent dosages of ferric chloride. It is evident from these curves that a fixed dosage of ferrigel would produce better over-all clarification through a period of wide fluctuation in flow and character of sewage because clarification is greater with partial dosages than when ferric chloride is used.

Conditioning sewage for coagulation by addition of a sensitizing colloid shows promise of greatly improved results from chemical treatment. The advantages which may be gained from such treatment are: lower chemical cost, easier control, and a decrease in the size of the units necessary for treatment.

It is questionable if the best method of sensitizing has been found. It is possible that an altogether different class of compounds than those employed in this work yield better results; perhaps a waste product itself could be utilized as a sensitizing agent. These results are reported more in demonstration of a principle of colloidal chemistry as applied to our problem than as the immediate development of a new chemical for sewage treatment.

Conclusions

1. Proteins in as low a concentration as 4 p.p.m. were found to reduce the amount of coagulant necessary for sewage clarification from 25 to 50 per cent and cause the formation of a ball-like floc that would settle despite agitation at flocculation speed.

2. Of several proteins tested, gelatin was found to give the best results although others gave a similar effect. The grade of gelatin employed did not affect the results appreciably.

3. A compound of gelatin and ferric chloride was prepared which had physical properties facilitating feeding and had excellent coagulating ability.

4. A similar compound was prepared using gelatin and aluminum chloride which was an effective coagulant. Other preparations made with compounds containing divalent metallic ions were not as effective for sewage coagulation as those made with trivalent compounds.

5. Ferric chloride-gelatin compounds yielded clear effluents equal or better than did ferric chloride in terms of B.O.D. (5-day), oxygen consumed, total bacteria and *E. coli*. The chlorine demand of the effluents obtained by the two methods of treatment was the same.

6. Gelatin-ferric chloride compounds gave good results when employed for dewatering ripe sludge but were not superior to ferric chloride alone for dewatering fresh solids.

7. The sludge obtained from treatment with the gelatin-ferric chloride compound could be dewatered without addition of chemicals for conditioning.

8. Pre-treatment of sewage with carbon dioxide prior to addition of ferric chloride-gelatin coagulant reduced the dosage required for complete clarification.

9. Return sludge did not aid this process of treatment. Flash mixing proved detrimental to the process reducing the size of the floc particles formed.

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Plant Operation

OPERATION OF SEWERAGE SYSTEMS AND SEWAGE TREATMENT WORKS FROM THE STANDPOINT OF NATIONAL DEFENSE *

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One immediate problem that faces municipal officials and sewage treatment plant operators in connection with the national defense program is the possible adverse effect of new or increased discharge of sewage or industrial wastes. The rapid expansion of existing industrial plants, new industrial plants, new or enlarged military establishments, and new housing construction for defense workers, may result in substantial increase in the amount of sewage discharged to municipal sewerage systems and treatment works. Where industrial wastes are discharged into existing sewerage systems or plans are made for the discharge of industrial wastes from new plants, the character of the wastes may interfere with sewage treatment plant operations. This may be true especially if the plant includes sludge digestion facilities. The efficiency of chlorine disinfection may be reduced by industrial wastes with excessive chlorine demand. Municipal officials should keep in close touch with proposed industrial plant expansions and proposed establishment of new industries. In questionable cases the advice of the state authorities should be sought. By advance planning, operating difficulties may be avoided. Treatment of wastes from defense industries before discharge to public sewers or exclusion of such wastes from public sewers may be necessary.

Federal, state and municipal officials have recently been giving a great deal of thought to questions of national defense as they relate to operation of public utilities. Of first importance comes to mind the protection of water, electric and gas utilities. However, the operation of sewers and sewage treatment plants looms in the picture of national defense because: (1) they are particularly susceptible to damage from present day war methods and (2) their interruption may have serious detrimental consequences to the public health. The discussion that follows takes up defense considerations which include problems of personnel and policing, property protection, possible effects of war damage, safeguards against the effects of power interruption, provision of duplicate equipment and supplies, emergency methods of sewage treatment

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plant operation, emergency repair of sewers, and health precautions after flooding with sewage or contaminated water.

In the water supply field, the Connecticut Water Works Association has a Committee on Water Works Defense, of which the writer is a member. This committee has worked in close co-operation with the state police, the public utilities commission and the state department of health. In the following discussion of precautionary measures, the writer has drawn to some extent on the material discussed and prepared by the Water Works Defense Committee in his state inasmuch as some of the factors involved are common to both water works and sewerage properties.

Co-operation with Police and Fire Departments

In considering policing, we should bear in mind that at the present stage, defense programs must contemplate the use of existing peacetime police agencies such as local police, state police and the Federal Bureau of Investigation. It is undoubtedly a good plan for the head of each public works agency to confer with the local police chief and the local fire chief so that the various interests along defense lines will be considered. State police departments in many states are also organized to investigate threatened sabotage and to furnish advice on defense measures.

Personnel

Checking Up on Personnel.—The importance of checking up on the background of all employees of public utilities as to citizenship and affiliations has been frequently stressed by responsible officials. Investigations have been made by most utilities and are certainly to be desired.

Identification of Employees.—Consideration has been given by many utilities to the provision of some satisfactory means of identification of employees for the protection of themselves and the public. While at the present time this may not be so urgent in the case of employees engaged in maintenance and operation of sewerage systems and sewage treatment plants, yet there is undoubtedly justification for taking preliminary steps along this line as a defense measure. The Connecticut Water Works Defense Committee has suggested two methods of preparing identification cards, one of which involves printing the employee's photograph directly on a card on which is also subscribed the pertinent information about the employee, and his signature. The second method involves the pasting of a photograph securely on a portion of a card and impressing a seal which extends partly on the card and partly on the photograph; the rest of the card has a space for information about the employee and his signature. For laborers, it may be desired to furnish badges rather than cards.

Duplicate Manpower.—In planning for emergencies it is often unfortunate that while duplication of equipment is usually given serious consideration, too little attention is paid to the need for human reserves. Even under normal conditions some of our sewage treatment plants are inadequately manned. Sickness or other unavoidable absence creates a serious operating problem. This lack becomes more acute when operating conditions become abnormal. Defense considerations should include the provision of reserve manpower. In a small town it may be possible to train some local plumber or other person to handle things in emergencies.

Protection to Property

Protection to Buildings.—This includes (*a*) window guards, (*b*) steel doors in lieu of wooden doors, (*c*) fencing around buildings. An especially heavy wire guard may be placed in windows of treatment plant buildings and pumping stations. Where heavy wooden doors are not replaced by steel doors, they should be equipped with pin tumbler locks instead of plain pin-locks. Vulnerable spots such as sewage pumping stations or treatment plants may be protected by installing "non-climbable" chain link fencing.

Protection to Property Outside of Buildings.—This may include (*a*) locking manhole covers over particularly vulnerable points on the sewer collecting system or at the sewage treatment plant, (*b*) locking valves and gates, and (*c*) fencing certain land that may afford approach to utility structures. Many exposed manhole covers have been locked by using a flat iron bar properly secured on either side of the manhole cover. Some manhole covers have been locked by use of special bolts. Manholes may be concealed from observation by covering with earth but in such cases provision should be made for prompt spotting of the manholes when access is necessary. Where valves and gates are in exposed positions, they may be pin-locked. In some cases wheels for operating gate valves have been removed to prevent tampering.

Floodlighting.—This may include the lighting of pumping stations or treatment plants. Floodlighting enables a patrolman to see readily the outline of buildings and therefore observe whether there is any unauthorized trespass around the buildings. In some cases lighting equipment is being set in place for use when desired even though for the present floodlighting is frequently being carried out intermittently rather than continuously. Police authorities usually express themselves as being in favor of continuous lighting, reinforced by patrol measures, rather than intermittent lighting. Where floodlighting is used it is important that the lighting should be trained on the approach to plant structures as well as on the structures themselves. Saboteurs do not need floodlights to guide them to vital points and the idea that lights will only draw attention to danger spots appears to have little backing from police authorities. In case of aerial bombing all lights, of course, would be blacked out.

Plant Visitors.—In peace time, encouragement has usually been given to the public to visit sewerage properties so as to become better acquainted with the facilities which are provided for public service. However, at the present time, defense considerations frequently outweigh the normal advantages of public education. It may be desired to work out arrangements with the central office of the Department of Public Works so that visitors who are not known to the plant attendants shall secure passes. Many utilities have extended the erection of "No Trespassing" signs to cover strategic locations on their properties. These serve to aid in keeping away unwanted visitors, including those who might photograph vulnerable structures.

Radio and Signal Devices

In the July, 1941, issue of the *Journal of the American Water Works Association* is a very interesting paper by W. Victor Weir discussed by W. W. Hurlbut, relative to the use of radio as a means of communication between distant points on utility systems. Signaling from loud speakers and sound trucks are used in directing utility operations in emergency.

Safeguards against the Effects of Electric Power Interruption

Sewage Pumping Stations.—In the operation of sewage pumping stations, reliance on one source of power is not desirable either in peacetime or war-time. Even in the case of usually dependable electric utilities, occasional interruptions of power are experienced. Sometimes this may be due to such accidents as damage to overhead wires in the vicinity of the pumping station. This hazard is reduced by placing wires in underground conduits. However, while all precautions of this nature should be taken, it is unquestionably desirable to have an independent source of power. Frequently electric power may be duplicated by direct connection from a Diesel engine or a gasoline engine. In some instances auxiliary electric power is generated by Diesel engines or gasoline engines. Portable pumping equipment driven by a gasoline engine or other means may temporarily take care of sewage pumping station operations. It may be possible to make connection of electric power lines to more than one transformer station should the usual station be put out of service. The present is an opportune time for responsible public officials to press for duplication of power in operation of pumping stations since a war emergency would unquestionably increase the hazard of power interruption. Power interruption may affect not only the operation of sewage pumping equipment but also some stations are so laid out that failure of sump pumps to remove drainage may put out of operation electric motors or other apparatus. Duplicate means of operating sump pumps or other arrangements should be provided if necessary for proper operation of the pumping station. The question of artificial lighting may also arise if electric current disappears. Portable lighting equipment may need to be provided. It may be desirable to work out plans for construction of by-passes above pumping stations where grades permit, whereby sewage would be by-passed in extreme emergency into watercourses that would not normally be permitted to receive such discharge on account of lack of dilution or other reasons. In most instances such by-passes need not be constructed unless conditions become acute and they should not be built just as an excuse in order to avoid the necessity for better, even if more expensive, preventive measures.

Sewage Treatment Plants.—As sewage treatment plants have become more and more highly mechanized, their operation becomes increasingly dependent on provision of power. In fact, in a large mechanized sewage treatment plant, there are so many motors and lights necessary for operation that it is doubtful whether anything but a separate means of generating electric power would overcome the handicap of interruption of a main electric power feeder line. Some muncipalities might wish to consider the provision of an electric generating plant for emergency. For short periods of time sedimentation tanks crippled by lack of power might be operated as septic tanks but for extended periods serious operating problems with handling of septic scum and sludge may develop.

Auxiliary Generating Units.—If it is not possible for a municipality to provide permanent auxiliary power generators, it may be possible to contact some equipment concern in the vicinity where an auxiliary generator can be secured in emergency. There is, of course, the disadvantage in such an arrangement that any limited supply of emergency generators might be exhausted when the utility wished to obtain one. However, a list of available equipment in the vicinity should be on record.

Chlorination in Case of a Power Breakdown.—One piece of equipment at the average sewage treatment plant that is frequently not dependent on electric power is the chlorinator. Therefore, should all other sewage treatment facilities fail and it becomes necessary to by-pass the treatment plant, it may still be possible to operate the chlorinator and heavily disinfect the raw sewage before it is discharged to any watercourse. While chlorine disinfection of raw sewage may not be entirely effective due to lack of penetration of some of the sewage solids and possibly a short contact period between the chlorine and the sewage, yet undoubtedly comparatively good over-all disinfection can be secured and this is a worthwhile step toward health protection. It may be well to consider the provision of extra rubber hose and fittings which would permit changing the point of chlorine application for emergency disinfection of raw sewage. If sewage effluent is pumped to solution feed chlorinators by electrically operated pumps, a stand-by connection from a public water supply or gasoline engine to operate the pump may serve to make chlorination possible when electric power fails. In extreme emergency chlorine gas or hypochlorites might be discharged into the sewage by a make-shift set-up if normal chlorinating procedures cannot be followed. One chlorinator manufacturer is producing a trailer truck with complete chlorinating equipment which may be readily transported for emergency use in the field.

Provision of Duplicate Parts and Supplies for Sewage Treatment Plants

Duplicate Parts and Equipment.—The operator should bear in mind that as production facilities become more and more taken up with turning out equipment for defense purposes, it will be increasingly difficult to obtain prompt shipment of parts for repair or replacement of sewage treatment plant equipment. Therefore, while an avalanche of non-emergency orders will probably help no one under existing conditions, particularly in those lines where production facilities are now being taxed to the utmost, plans should be laid for emergencies. It is difficult to list all of the spare parts and equipment that are necessary in connection with operation of machinery and devices at sewage treatment plants and sewage pumping stations. However, the following are suggested as some of the items:

Ball valves for sludge pumps
Shear pins
Fixed and moving electrical contacts (at least one set, six for 3-phase)
Extra set cutters (both fixed and movable for comminutors or shredders)
Few extra links for drive chains and for scraping chains. Pins for chains
Two extra flights (cedar, redwood, or metal)
Wearing shoes
Incinerator parts
Fusible plugs for flame traps
Set of brushes for fine screens
Set of gaskets, packing, and lead washers for chlorine cylinders
Pressure reducing gas inlet valve for chlorinators
Extra bell jar for chlorinators
Extra head tube for chlorinators
Chlorinator pressure reducing valve union assembly
Extra valves and flexible connections for chlorine feed lines
Nozzles for fixed spray trickling filters
Aluminum bolts for diffuser plate holders
Extra carborundum diffuser plates
Valve channels and valve springs for vacuum pumps
Discs for protectostats on heating equipment
Mercury tubes for relays
Additional belts for Reeves drives

It would be helpful in preparing a list if the operator would review those parts which he has had to obtain in the past two or three years to take care of breakdowns or replacements. This does not mean, however, that consideration should not be given to those parts of the machinery and equipment that have not yet given trouble but may give trouble in the not-too-distant future.

Supplies.—In the older type of sewage treatment plant such as an Imhoff tank-sand filter plant, necessary supplies are at a minimum. With many modern treatment plants, however, a steady stream of supplies is necessary for plant operation. This applies particularly to those plants where sludge is dewatered on vacuum filters. If the supply of chemicals were interrupted, the plant might need to be shut down. Every effort should be made to have available such supplies as the following:

Packing for sludge pumps
Packing for sewage pumps
Lubricants and special oils
Special insulating oil for oil immersed switches
Fuses
Adequate supply of chlorine cylinders
Packing for chlorine valves
Cloths, wire, ferric chloride and lime for vacuum filters
Portable lights
Gaskets
Mercury
Chemicals and glassware for laboratory
First Aid Kit

Priorities.—The water works profession, especially through the American Water Works Association, is keeping in close touch with the application of priorities in delivery of materials and equipment as they may affect operation of water systems. Possibly the Federation is doing or can do a similar service in the field of operation of sewerage systems through its officers or a special committee.

The Office of Production Management (O. P. M.) has district offices, mainly for informational purposes, in various sections of the country. The usual procedure for making requests for priorities in shipments of materials has in the past been to submit a form known as P.D. 1 to the Director of Priorities, Office of Production Management, Washington, D. C. This form consists of two sheets to be made out in quintuplicate, four copies to be sent to the Director of Priorities, Washington, D. C., and the fifth to be retained by the applicant. On the form the name of the applicant, the person or firm from whom the materials are to be obtained, the requested delivery schedule, with other pertinent information are called for. However, the priorities situation as affects water and sewer utilities has been greatly changed recently by the issuance by the O. P. M., of Preference Rating Order P–46. Under this order managements of water and sewer utilities may immediately secure a preference rating for materials which are essential to *operation* and for *certain limited expansion* as defined in the order. The management of each water or sewer utility should secure a copy of this order.

Order P–46 provides for a form of acceptance which must be executed by the head of every water or sewer utility in order to put the preference rating in effect for the utility concerned. This acceptance form must be submitted to the Power Branch, Office of Production Management, Social Security Bldg., Washington, D. C. After the acceptance form has been filed, each order form filed by the utility should bear the endorsement "Purchase Order for Utilities Operation Maintenance and Repair, Preference Rating A–10, pursuant to Preference Rating Order No. P–46." While the automatic application of the preference rating to orders does not of itself insure prompt deliveries as there are other higher preference ratings, and many considerations of availability of supplies are involved, it does work to promote replacement of materials needed by suppliers to fill orders.

There has also been established by the O. P. M. a procedure for assigning preference ratings to specific projects such as a new major sewer extension or a new sewage treatment plant. This might particularly apply in the case of some project which is closely related to defense industry, defense housing or demands created by defense activities. If it is desired to seek such a project rating, a letter of application should be addressed to the Director of Priorities, Office of Production Management, Attention: Project Priority Group, 462 Indiana Avenue, Washington, D. C. The letter should contain a complete description of the project together with the cost and proposed dates of construction, with special stress on such considerations of defense or other emergencies as may exist.

Chlorine and chlorine compounds for disinfection of water and sewage were given a preferential rating some time ago and so far no difficulties have been reported in Connecticut. If there is any trouble with local distributors or middlemen, it is suggested that contact be made directly with the manufacturers. Chlorine manufacturers have stressed the need for prompt return of containers and the avoidance of unnecessary hoarding of containers.

In the case of other chemicals widely used in sewage treatment plants such as ferric chloride and lime, no serious difficulties have yet been reported in the writer's state. Application for preferential shipments under Preference Rating Order P–46 should help in insuring delivery of chemicals. In case of future trouble, perhaps the assistance of the office of Defense Health and Welfare Services, headed by the Federal Security Administrator, Paul V. McNutt, might be secured to promote special consideration of shipment of chemical supplies to sewage treatment plants. Already sewage plant operators are feeling the pinch of securing replacement of repair parts; certain types of wire for holding filter cloths are no longer obtainable.

Emergency Methods of Sewage Treatment Plant Operation

Reference has already been made to temporary operation of mechanically-cleaned sedimentation tanks as septic tanks for short periods of time where power facilities fail and to use of chlorine disinfection as a stop-gap if other methods of treatment should be impracticable.

Where several settling tanks are normally operated in parallel, an emergency might justify sending all the sewage temporarily through a reduced number of tanks and then shifting the load to other tanks. While the efficiency of sedimentation would be thus reduced, the more offensive larger solids would be removed. Chlorine might be applied to a tank effluent in emergency in place of secondary biological treatment.

Breakdown of sludge dewatering supplies or equipment might necessitate lagooning of sludge with heavy application of lime or chloride of lime to keep down odors. One or more of a battery of settling tanks might be discontinued from sedimentation service, for temporary use as sludge storage or partial digestion tanks.

It is obviously not feasible to detail what can be done at each individual plant due to varying conditions but certainly each plant operator should review in detail how sabotage, direct war damage, loss of power or lack of supplies or replacement parts might affect his plant and see what plans he can devise to keep the plant in at least partial operation in emergency.

Example of Costs of Defense Precautions for Treatment Plants and Pumping Stations

In one Connecticut community with a population of approximately 35,000 persons, a careful study has been made of defense steps that are needed for sewage treatment plants and sewage pumping stations in the town. As an example, the following is quoted from their estimates:

Emergency supplies and equipment	$ 600
7 pumping station overflows	2,100
Gas engine (1 pumping station)	700
12 sets of gate valves and back water valves on house soil lines	600
1 overflow at treatment plant	200
1 portable generating set on trailer	4,000
3 fireproof chlorine shelters	13,500
Portable lights	100
600 g.p.m. portable pump	800
General emergency fund for extra labor and unforeseen equipment, supplies, materials and contingencies	4,000
Trunk sewer relief	1,500
4 fire extinguishers	200
Total	$28,300

Types of Damage from Military Operations or Sabotage

Sewage Pumping Stations and Sewer Collecting Systems.—Sewage pumping stations may be damaged directly by aerial assaults or by sabotage or may be put out of commission through damage to power facilities. Damage to sewer collecting systems may involve damage to sewers because of aerial assaults or because of sabotage through the use of explosives or through obstructions placed in sewers. Sewers are, of course, very vulnerable to aerial attack. According to information received from abroad they are sometimes damaged to a distance of 60 to 120 feet from outside of the crater produced by the bomb. In many cases craters only 10 to 15 feet in width have damaged sewers 25 to 40 feet under the surface. These depths refer to sewers lying below paved roads with concrete foundations.

It has been found that a 1000 lb. bomb dropped from 20,000 feet in clay soil will penetrate from 30 to 40 feet. The average for a 100 lb. bomb is 11 feet penetration; 500 lb., 15 feet; and for a 1000 or 2000 lb. bomb, 22 to 25 feet. It would be necessary to go 60 feet in clay type soil with a cast iron roof to be protected from a 1000 lb. bomb.

Sewage Treatment Plants.—Damage to sewage treatments plants may be caused by aerial assault or by sabotage through use of explosives or through tampering with plant machinery or structures; operation of treatment plants may also have to be suspended because of damage to power facilities or interruption of transportation facilities whereby it becomes impossible to secure necessary supplies.

Possible Effects of Damage

Effects that we may foresee from damage to sewer collecting systems, sewage pumping stations or sewage treatment works which may create defense emergencies are:

(1) Discharge of sewage to water supply tributaries either through sewer breaks or emergency overflows or through failure of sewage treatment facilities to function.
(2) Discharge of untreated sewage to bathing areas or to shore waters used for harvesting of market shellfish.
(3) Flooding of streets, cellars or buildings by sewage.
(4) Interruption of use of toilet facilities where these facilities have to be abandoned because of difficulties with disposal of discharges from them.
(5) Pollution of streams used for water supplies by manufacturing plants.
(6) Escape of large quantities of chlorine from damaged containers.
(7) Escape of sewage from broken sewers, into water pipes or gas mains.

There are not listed odor nuisances nor exposure of sewage material where fly-borne infection might result, for the reason that these are undoubtedly less serious immediate emergencies than those listed above. However, it should be borne in mind that these considerations have an adverse effect on health and well-being and they should certainly be taken into account over any extended period of time.

Emergency Repairs of Sewers

Emergency Steps in Case of Sewer Breaks.—Judging from the limited reports of conditions abroad, breaks in sewers have been one of the principal sources of trouble in connection with the operation of sewerage systems. These have been due to aerial assault. It is difficult to lay plans in advance for taking care of such conditions. However, value will undoubtedly result from giving some consideration as to steps that may be taken.

In the case of breaks in large sewers it may be necessary temporarily to excavate material, including broken sewer casing, from the sewer trench and allow the sewage to flow in an open channel until the break can be repaired. The repair of the break may involve use of emergency pumping facilities whereby the sewage is temporarily pumped over ground from the manhole above the break to a manhole below the break. If there is any watercourse or storm sewer nearby, it might be possible temporarily to by-pass sewage into the watercourse or into the storm sewer. In such cases, the management of the utility should make certain that the health authorities are consulted so that in the event that any adverse health conditions might result from the by-pass, steps may be taken to warn the public or carry out other protective measures. Emergency pipe lines of iron, steel, or asbestos cement can be quickly constructed overground with the use of couplings. Wooden flumes may also be quickly set in place to provide means for temporary discharge.

According to reports from abroad, precast tubes have been used to replace large sewers, being subsequently lined with one ring of brickwork. It is assumed that these have been installed more or less in the nature of sleeves over the broken pipe. Presumably in this country sections of concrete pipe which can be obtained in lengths of 4 ft. to 8 ft. and in diameters up to 72 inches could be used for repair sleeves on sewers with the aid of cement. A committee of the American Society of Civil Engineers and others have been working on development of certain specific plans for quick repairs of sewers.

Organization for Emergency Sewer Repairs.—It is usually a good plan to give consideration to the contractors in any vicinity who may be available to provide the necessary skilled help, equipment and supplies to make emergency repairs. It is suggested that in any community there be available not only a list of contractors who might be called on but also, so far as possible, a list of the equipment which these contractors carry in stock.

In many communities there are licensed drain layers whose business it is to install house sewers. It would seem that in any emergency program for repairs of public sewers, these drain layers might be organized to render considerable assistance. Local plumbers may also be called upon. In one report from England, mention is made of the fact that where emergency crews have been organized to close and open water distribution valves, such crews have often been recruited in part from among the local plumbers.

Among recent happenings in the New England area, perhaps the nearest resemblance to what we might be called upon to face in case of aerial bombardment was the immediate after-effect of the 1938 hurricane. Then public works officials had to organize emergency crews to clear streets and carry out other emergency tasks. In some cases cities were divided into areas in which different groups worked. For defense purposes, crews might be set up to cover different parts of a city. Presumably, some plan for a pool of laborers must be worked out.

Portable lighting equipment is among the necessities. Frequently this may be operated by a generating unit powered by gasoline engine. If gas mains were struck and gas seeped into the sewers, the explosion hazard would have to be considered. Lighting from storage batteries might in such a case be the best plan.

Emergency Supplies for Repairs.—In the water works field in Connecticut, the State Department of Health is co-operating with the Connecticut Water Works Association and the public water supply officials on the keeping of a central inventory of water works supplies which may be of use in emergency. It does not appear that the situation in the field of sewer collecting systems and sewage treatment justifies a plan for a central inventory. However, each local official should bear in mind those items of sewer maintenance equipment that would be needed for emergency. Following is a partial list of sewer maintenance equipment that is usually kept on hand in the larger sewer departments:

Sewer cleaning rods
Portable power pumps with suction and discharge hose
Portable hand pumps
Portable lights
Jointing compounds
Tile pipe in various sizes
Warning signs
Steel, iron or asbestos cement pipe with couplings for emergency pumping
Trench jacks
Paving breakers
Compressors with gasoline engines
Brick, cement, sand and gravel
Manhole and catch basin castings
Reinforcing steel
Hardware, including nails, bolts and nuts
Grease and oils
Waste
Valves
Rubber boots, coats, hats, gloves
Dynamite and blasting caps
Shovels
Picks
Bars
Trowels
Hoes
Axes
Drills, hammers, mauls
Rope with hook attached
Scrapers
Saws
Derricks
Chain and falls
Water pipe and water hose
Pails
Lanterns and batteries
Canvas
Wheelbarrows
Rope
Wire cable
Chains
Lumber
Fuses
Gasoline and kerosene

Damage to Chlorine Containers and Provision of Gas Masks

No information has become available as to aerial damage to chlorine containers but conceivably a serious situation might be created if a large number of ton containers were hit by bombs. Even sabotage might create a serious situation. Consideration should be given in the storage of containers to possible damage. It might be advisable to consider decentralization of a large stock of chlorine ton containers should conditions become acute. Specially constructed shelters for supplies of chlorine are being considered in some localities. It is also important that the operators of sewage treatment plants review occasionally what steps might be taken in the case of handling of large numbers of leaking containers. At least two gas masks, stored in a readily accessible place, should be available at any plant where chlorine cylinders are stored.

Health Precautions in Cases of Flooding by Sewage

In the Connecticut floods of 1936 and 1938 there was considerable experience with damage to homes and home furnishings, food stores and eating places caused by flood water polluted by sewage. Therefore, some of the precautionary measures which were suggested at that time are worth repeating in this discussion. If the operation of sewers becomes interrupted, there is, of course, the danger of contamination by flooding with sewage.

Chlorine Disinfectants.—For serious flooding with sewage, a solution made up of water and chlorine is probably the best disinfectant to use. The chlorine is usually best made available by the use of some chlorine compound such as chloride of lime or a high test calcium hypochlorite powder (for example, HTH, Perchloron, Chlorofex, etc.). In the figures quoted below, reference is made to dosages of chloride of lime. The chloride of lime should be fresh and not have been exposed to the atmosphere. If instead of chloride of lime, a high test chlorine powder is used, about four tenths of the amount of chemical specified should be effective.

It is a precautionary measure to find out locally where chloride of lime (or chlorinated lime) or high test chlorine powder—not ordinary unslacked lime or hydrated lime—can be obtained. Sometimes disinfectants may be obtained from local chemical supply houses. In other cases, it may be necessary to secure the chemicals from some distance. Inasmuch as some deterioration takes place if these chemicals are stored over a long period of time, the accumulation of large supplies in local storage places may not be desirable, although for a period of six months to a year good protection is provided by storage of limited supplies. Sometimes operators of local swimming pools or of water treatment plants may have some supplies of chlorine disinfectant available.

Cresol Disinfectants.—If chloride of lime is not used, such disinfectants as lysol or cresol may be used to wash down any surfaces exposed to flood water and sewage. Four tablespoonsful or two ounces of such disinfectants per gallon of water may be made up for a disinfecting solution. Care should be taken to avoid burns which may be caused by full strength of the disinfectant without dilution with water.

Pollution of Water Mains.—The disinfection of water mains polluted by broken sewers is normally handled by the municipal water department and will not be discussed in detail here. Dosages as high as 50 p.p.m. of available chlorine are frequently applied to polluted water mains through the use of hypochlorites or chlorine.

Flooded Cellars.—After flooded cellars are drained or pumped out, they should be washed down with a hose with clean water and brushed and scrubbed. Then a disinfecting solution of chloride of lime and water may be applied with a brush, broom, rag or pressure sprayer, the latter being the quickest and most effective. Such a solution can be made up with one pound of chloride of lime in six to ten gallons of water. It is not advisable to throw chloride of lime into a lot of cellar water as the strength of the disinfectant will be rapidly wasted by the dilution. The cellar or house should be cleaned out first.

Flooded Furniture.—The following precautions are suggested:

Curtains—(*a*) Boil all that can be boiled without injury to fabric.
(*b*) Dry thoroughly in the open air and sunshine.
(*c*) Press with hot iron, or dry clean.

Rugs—(*a*) Flush off with clear water while still on floor.
(*b*) Dry thoroughly in the sunshine.
(*c*) Use a mild soap and luke warm water to shampoo—then rinse and dry.

Furniture—(*a*) Wash with strong soap and water all surfaces that can be reached and will not be harmed, such as wood, metal, leather, cane and composition materials.
(*b*) Upholstered materials. Wash whatever materials can be surface-washed and dry thoroughly, preferably in open air and sunshine.

Discard whatever cannot be cleaned and dried such as badly soaked mattresses and upholstered material.

Flooded Clothing.—The following recommendations are made: Boil immediately everything that can be boiled without injury. Otherwise, dry thoroughly, in the sunshine, all clothing that cannot be boiled. Then sterilize by pressing with a hot iron or by dry cleaning.

Flooded Foodstuffs.—No foodstuffs subjected to contamination from sewage should be used unless such foodstuffs have been stored in watertight containers, in which case the outside should be thoroughly sterilized with boiling water or disinfectant. It is best to "play safe" and discard any questionable foodstuffs. No flooded foodstuffs should be sold to the public.

Flooded Wells.—In some localities sewage overflows may contaminate wells and springs. In such cases, they should be disinfected with a solution of chloride of lime and water. Twelve to sixteen ounces of chloride of lime (or about four tumblersful) dissolved in a pail or two of water strained through cloth and poured into an average size dug well will disinfect it heavily. It is also desirable to wash down the side walls of a well with a disinfecting solution above the water line. Large quantities of the disinfectant are not injurious. The chlorine odor will soon disappear. Effort should be made to stir up the disinfected well water and it should be allowed to stand for thirty minutes to obtain adequate contact. If the well has been badly polluted, it is safer to pump it out after disinfection and disinfect it again. Any debris entering the well should be removed. Users should boil for five minutes all well water that may be polluted, until the well is disinfected and it is certain the water is safe, to avoid water-borne typhoid, dystentery and diarrhea.

Precautions by Emergency Workers.—Workers should be cautioned to guard against infection. They should not get their hands near their mouths, eyes or noses, after handling polluted surfaces or polluted water until their hands have been washed with soap and clean, preferably hot, water. They should also not handle food without clean hands.

Typhoid Immunization

It is well to remember that workers who may handle materials contaminated by sewage should be immunized against typhoid fever and this, of course, applies to employees engaged at work in sewage treatment plants or in connection with maintenance of sewerage systems. These precautions seem all the more necessary at times when defense measures are under consideration.

First Aid

Workers may be subjected to injuries in war time during repairs to sewers or while operating sewage treatment plants, or may on arriving at the scene of a sewer break have occasion to render first aid. First aid courses have been and are being given by the Red Cross and other agencies to laymen in order that serious bleeding, unconsciousness and poisoning of victims may be properly treated until a doctor can be secured. It would be well to have operators arrange for first aid courses for as many of their assistants as possible and to provide safety kits for their use.

Every plant superintendent should have posted in a convenient place the telephone numbers of physicians, police department, fire department or other agencies that might be needed in emergency. It is recommended that the locations of nearby places where inhalators can be secured be obtained and posted along with other information.

Along with first aid measures should be considered the question of emergency fire fighting facilities. Extinguishers should be available and employees should be trained in emergency fire fighting measures.

Conclusion

While we sometimes hear expressions that we are spending too much time on defense considerations in too many fields, the writer cannot agree with these objections. As a matter of fact, many features of defense preparedness deserve consideration as peace-time precautions against possible disasters that may be unrelated to war. And if war comes, no wars have ever been won by waiting for the other fellow to surprise you.

This outline of precautionary measures to be considered in the operation of sewerage systems and sewage treatment works from the standpoint of national defense is by no means complete. It is hoped, however, that it will bring up for discussion some of the many phases deserving study.

Acknowledgments

In preparing this discussion of emergency measures, the writer wishes to make acknowledgment of the material drawn up by the Defense Committee of the Connecticut Water Works Association, the assistance of Mr. John H. Brooks, Jr., Superintendent of Sewers of Worcester, Massachusetts, in discussing sewer maintenance, and suggestions as to provisions of supplies and equipment at sewage treatment plants which were received from two or three of the Connecticut sewage treatment plant superintendents through Mr. L. W. Van Kleeck of the Connecticut State Department of Health.

Discussion

By Paul Hansen

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Mr. Scott's paper is the most thorough review that has yet appeared covering defense measures for maintaining sewerage and sewage treatment works in operation during periods of warfare and threats of warfare. His catalog of damages that may result from sabotage or attack seems to cover every contingency and his list of parts and supplies to be maintained on hand for the repair of damage is excellent.

The keynote of all protection of public utilities in connection with defense should be the winning of any war in which we may become involved. Hence, there should be a minimum of diversion from war preparation and industry and a minimum diversion of personnel that may affect the defense effort. Six essentials are necessary for effective defense and effective waging of war, namely, ships, aeroplanes, guns, ammunition, tanks, and trained men. Anything else is of secondary importance and should be adjusted in a manner not to interfere with defense needs. Our point of view should be directed to defense and not to perfect services from utilities and not to conveniences not essential to defense. Of course, it is well to review all the possibilities of damage to sewerage and sewage disposal works, as Mr. Scott has done; but actual measures to protect a sewerage utility should be tempered with proper regard for the fundamental needs of the country in matters of defense.

So far as sewerage is concerned, injury to sewers in streets, especially trunk sewers, constitutes the greatest menace to public health, public comfort and possibly even the military effort itself. Therefore, first attention should be directed to prompt repairs of any street sewers that may be damaged by sabotage or military attack.

Some sewage treatment plants have a direct bearing on public health, such as those protecting water supplies, shellfish layings and streams used by dairy cattle; but most of them are built for nuisance prevention or nuisance abatement. Even if out of service for a period of time, no lives are likely to be lost and nuisance prevention, at least temporarily, can be well subordinated to defense requirements. The performance of some sewerage systems is dependent upon continuous pumping; but this is unusual. More often there is some form of gravity by-pass or overflow that will permit the functioning of the sewers if the pumping station is damaged or destroyed. Where, however, dependence must be placed upon the continuous operation of a pumping station, naturally some special methods should be adopted for its protection against sabotage or attack.

Among the utilities, sewerage and sewage disposal is of lesser importance to the continued functioning of the city and the military establishments within the city, than are most other utilities. Sabotage of sewage treatment works is not likely, because the military advantage of this form of attack is too small. Sabotage of sewers, however, may be damaging, especially if the sewer removes wastes from an important defense industry.

In a letter under date of August 20, 1941, a prominent British engineer * reflects somewhat the British point of view. He writes as follows:

In reply to your letter dated 14th July, which only arrived this morning, I would suggest that the most effective way of protecting your sewage system and sewage treatment plants is to make more bombers, more fighters, and more ships, and thank the Almighty for the Atlantic and Pacific Oceans.

"Punch" values the English channel to us at a guinea a pint, so on the same basis the value of the two oceans to your country must make your defense expenditure seem like the cost of a postage stamp.

Joking apart, I should not attach too much importance to the risk of bomb damage to sewerage systems and sewage treatment plants. It is only in the case of an unlucky hit on a large pumping installation that the damage might be serious.

Fortunately a Sewage Works is difficult to damage by high explosive, or to set on fire.

I would suggest that the things to look to are:

1. Provision of a reasonable stock of repair materials, such as cement, bricks, pipes, timber, valves, etc.
2. An efficient "black-out" scheme, either by inside shuttering, or by the use of a colored lighting scheme. (Amber lighting and blue windows.)
3. Air raid shelters for personnel, either improvised in existing buildings, or by surface shelters.
4. Provision and equipment of First Aid Posts, and the training of a large proportion of the older men in First Aid work. (The younger men will be taken away for fighting services.)

* Mr. H. C. Whitehead, Engineer to the Birmingham Tame and Rea District Drainage Board, England.

5. A fire watching and fire fighting organization. (All employees and staff between the age of 18 and 60 should take their turn in these duties.)

Our greatest difficulty is shortage of men for repair work. Naturally all the younger men and many of the middle-aged ones are in the Services or on armanent work, and we have to content ourselves in many instances with improvised repairs.

We, with other Local Authorities in the Midlands, have a mutual aid scheme, in which we can call on each other for help in repair work after a bad raid. So far we have not made use of this scheme, but a similar scheme for fire fighting has been most helpful.

I am sorry I cannot send you actual figures and photographs, but you will understand the reason for this.

In the light of these comments, it appears that Mr. Scott's suggestion of a central inventory of supplies is an excellent one and in line with the economical use of materials not essential to defense effort. The use of contractors for making quick repairs is likewise a practical and valuable suggestion. No doubt in this connection Mr. Scott favors not merely maintaining a list of contractors but favors some definite understanding with contractors so that they might be available on short notice with appropriate equipment and crews of men.

The greatest value at this time of Mr. Scott's paper is the searching analysis he has made of the protection of sewerage systems, which, when the time of danger arrives, will constitute a sound basis for developing practical protection.

DISINFECTION OF SEWAGE BY CHLORINATION *

By G. E. Symons and R. W. Simpson

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With the inception of sewage treatment at Buffalo, N. Y., on July 1, 1938, it became possible to collect data on the effectiveness of sewage chlorination for disinfection on a large scale. This paper presents a summary of the results of plant operating data covering 11,000 bacteriological analyses during a period of 31 months. The statistical study of these daily data and monthly averages makes it possible to evaluate the effectiveness of chlorination and the method of control used (1), to compare plant operating results with experimental studies (2), and to indicate the part sewage chlorination has played in reducing the bacterial pollution of the Niagara River (3, 4).

Descriptions of the physical factors of the sewage treatment plant and its operation, their effects on the variations in the chlorine demand of the sewage, and upon the methods of dosage control, have been described in previous papers (1, 5) from the Bird Island Laboratory. After a very short period of two to three minutes during which air is blown through the sewage in the conduits, chlorine solution is added, from one to two minutes before the sewage is discharged into sedimentation tanks. Dosage of chlorine is controlled hourly by determinations of the chlorine demand of the raw sewage and by the use of proper dosage factors to relate the demand of one hour to the dosage for the next, taking into account seasonal variations (1). Check of the control is the maintenance of a residual of 0.1 p.p.m. of chlorine, 15 minutes after the addition of the chlorine solution to the sewage. The method of determining chlorine demand is that developed in the Bird Island Laboratory in 1937 (6) and the spot plate technique is used for determining residual chlorine. Checks of the dosage are made by testing samples of the influent to the clarifiers and of the plant effluent at hourly intervals.

Technique of the Study

Samples of raw sewage and plant effluent are collected at five different hours each day, as follows: For the raw sewage—8 A.M., 10 A.M., 1 P.M., 3 P.M., and 2 A.M.; for the effluent—9 A.M., 11 A.M., 2 P.M., 4 P.M., and 3 A.M. Recently an additional sample of each has been added to the routine. The difference between the sampling times for the influent and effluent allows for contact time in the clarifiers. Except that this interval is slightly longer than the probable average contact time (see later discussion), the sample of the effluent roughly represents the chlorinated and settled sewage which is comparable to

* Presented at the Spring Meeting of the New York State Sewage Works Association, Niagara Falls, June 19–21, 1941.

the raw sewage of the previous hour. The hours at which the samples are collected were chosen for the specific reason that both preliminary studies (7) and plant studies (5) on the variation in chlorine demand indicated that these hours represented certain definite conditions, *i.e.*, minimum concentration of sewage at the beginning of the day; sewage of average concentration during the morning; sewage of maximum concentration about noon; sewage of more than average concentration in the afternoon; and slightly below average concentration in the early morning. These hours also represent relatively similar conditions as to concentration of coliform bacteria.

It was reasoned that if the method of control of chlorine dosage used (1) produced proper disinfection at these hours, then the same method of control throughout the day would produce similar disinfection results at all other hours of the day. Furthermore, it is believed that these five samples represent fairly well a most probable average concentration of bacteria.

With the exception of the samples taken at 3 and 4 A.M., all samples were cultured immediately for coliform tests. The early morning samples were refrigerated until 8:30 A.M. The chlorinated effluent samples were collected in sterile bacterial bottles containing thiosulfate, for the purpose of stopping any further action of chlorine on the bacteria after the sample had been collected. During the first year, in addition to the determination of coliform bacteria, the total bacterial count was determined on agar plates. The most probable number (M.P.N.) of coliform bacteria was determined by the serial dilution method (8) using three tubes in each of three dilutions in the chlorinated sewage and three tubes in two dilutions in the raw sewage. Confirmation of positive tubes was made at 24 and 48 hours in brilliant green bile lactose broth. Data on both raw sewage and plant effluent were reported as 1000 coliform per ml. and in order to obtain the proper average, all average bacterial data were weighted according to the flows existing at the time of sampling. Weighting was done by the use of quantity units $\left(\text{Q.U.} = \dfrac{\text{Bacteria per ml.} \times \text{c.f.s.}}{1000} \right)$.

Analytical Results

It has been reported by us that a determination of chlorine demand of sewage cannot be made on composite samples (5, 7). The same has been found true of the determination of total bacteria and coliform bacteria in raw sewage and chlorinated effluents. This is illustrated by the data shown in Table I, which is a comparison of the bacterial content of refrigerated composite samples with the average of individual samples. Comparisons available for twelve months indicate that compositing tends to increase the total count of raw sewage about 14 per cent, while the coliform bacterial content increases about 22 per cent. In the case of chlorinated effluents the increase in the total count was 157 per cent and the coliform content increased 148 per cent. In other

TABLE I.—*Comparison of Bacterial Content of Refrigerated Composite Samples with the Average of Individual Samples*

Results per ml.

Month 1938–39	Raw Sewage				Plant Effluent			
	Total Count		M.P.N. Coliform		Total Count		M.P.N. Coliform	
	Comp. Data	Avg. of Ind. Samples	Comp. Data	Avg. of Ind. Samples	Comp. Data	Avg. of Ind. Samples	Comp. Data	Avg. of Ind. Samples
Sept.	1,963,200	1,774,500	286,700	216,200	123,900	25,580	7,390	650
Oct.	1,846,000	1,292,600	152,200	88,100	125,600	25,520	10,350	1,660
Nov.	1,223,000	861,000	63,300	74,300	115,300	28,510	3,950	1,280
Dec.	238,000	215,000	32,100	37,900	1,840	960	280	140
Jan.	—	—	34,320	40,100	—	—	20	20
Feb.	101,200	86,800	15,400	19,200	1,710	1,860	230	250
Mar.	77,800	109,400	16,100	24,500	3,840	3,200	1,060	460
Apr.	99,740	112,100	21,400	36,400	7,030	6,450	2,480	2,230
May	199,600	187,000	41,200	53,100	5,050	9,630	1,520	880
June	500,800	271,200	134,400	84,000	23,540	22,160	560	620
July	1,137,000	484,600	143,500	191,400	27,540	7,660	1,660	1,000
Aug.	1,624,000	2,020,000	351,900	163,600	44,760	30,830	3,240	920
Sept.	1,169,000	1,454,000	147,900	141,800	29,110	36,120	3,480	3,960
Average	846,000	740,000	110,100	90,000	42,400	16,500	2,780	1,080
Increase of Composite over Average of Individual Samples	14.3%		22.3%		157%		148%	

words, the total count and coliform content of refrigerated composites are approximately two and one-half times the average of individual samples for the same period. Probably a contributing factor in this increase is the fact that the residual chlorine does not persist in the sample after compositing, thereby allowing regrowth to occur with the production of chlorine demand. If a residual were maintained, the data would be incorrect for in effect the contact period would then be the average composite period. These results clearly indicate that the use of refrigerated composite samples for the determination of bacterial kill by chlorination is not permissible.

Whereas the variation of chlorine demand of sewage lagged behind the variations in the temperatures of the sewage (5), it was found that the coliform content followed an almost identical curve with the variation in the temperature of the sewage. The maximum occurs in the late summer months and the minimum in the early spring. The effect of temperature on the coliform content of the raw sewage is shown by the data in Table II, plotted in Fig. 1. This figure also includes a curve of the effluent content of coliform by months and shows that this effluent content is independent of temperature or bacterial population variations

TABLE II.—*Variations in Coliform Content of Raw Sewage with Temperature*
M.P.N. per ml.

Month	1938		1939		1940		1941	
	Temp. ° F.	Coliform Bact.	Temp. ° F.	Coliform Bact.	Temp. ° F.	Coliform Bact.	Temp. ° F.	Coliform Bact.
Jan.			47.3	38,800	48.7	45,300	48.8	28,200
Feb.			45.2	17,900	46.7	36,400	47.6	26,200
Mar.			45.8	20,300	45.4	24,700	46.3	28,200
Apr.			47.9	30,800	48.5	29,100	51.8	35,000
May			56.3	48,800	54.8	37,800		
June			66.1	74,200	64.2	61,400		
July			72.0	173,500	69.5	91,600		
Aug.			74.7	171,000	72.5	117,000		
Sept.	71.0	218,000	70.8	135,000	68.4	120,000		
Oct.	65.0	90,000	65.4	79,000	64.2	63,600		
Nov.	57.5	78,700	58.8	52,000	55.9	33,600		
Dec.	50.2	44,700	52.8	51,400	49.2	27,300		
Average	60.9	120,300	58.6	74,500	57.3	57,100	48.7	29,400

in the raw sewage. The difference between the curves for raw sewage and effluent indicates the effectiveness of sewage chlorination at Buffalo.

The bacterial content of sewage varies with the hour of the day and this variation is dependent upon the temperature. The effect of the

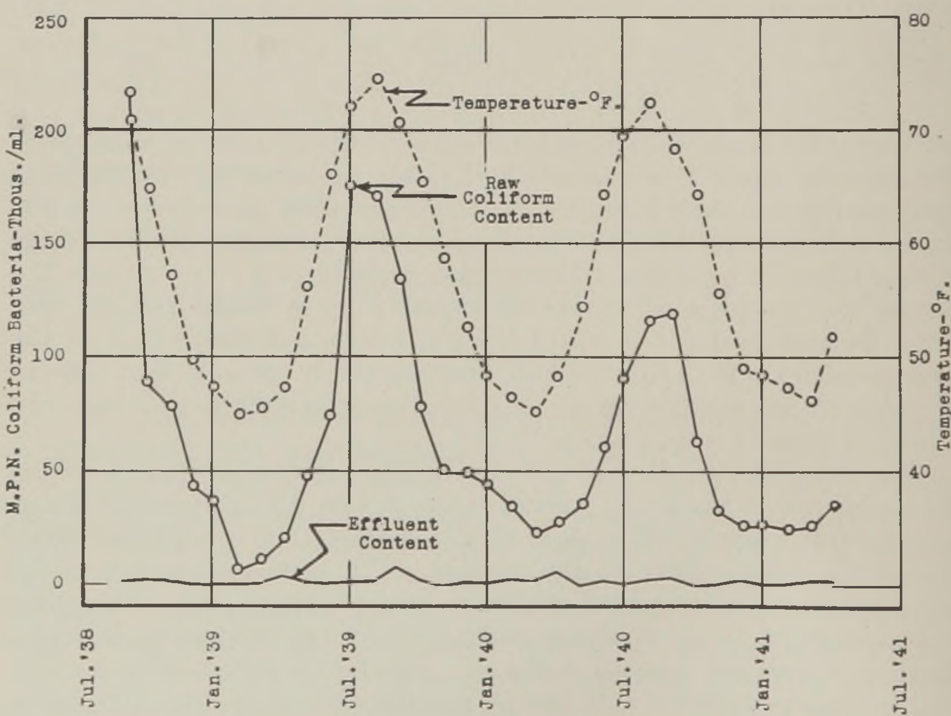

FIG. 1. Variations in coliform content of raw sewage with temperature.

time of the day or strength of the sewage on the bacterial content of the sewage is shown by the monthly average data in Table III and the plot of these data in Fig. 2. The months were grouped into seasons in accordance with the indications of the curves in Fig. 1. It is interesting to observe that the trend of the curves, *i.e.*, the concentration of coliform bacteria, follows the same trend as the chlorine demand although the two probably have little actual relationship (9). The chlorinated effluent content is not affected by these variations with time any more than with those of temperature. An inspection of the data indicated that there is apparently little difference in the coliform content of raw sewage from day to day, except that with the weaker sewage of Sundays, the coliform content is lower.

TABLE III.—*Hourly Variations in Coliform Content of Raw Sewage by Seasons*
M.P.N. per ml.

Season	Minimum Content	Increasing Content	Maximum Content	Decreasing Content	Avg.
Hour	Dec.–Jan. Feb.–Mar.	Apr.–May June	July–Aug. Sept.	Oct.–Nov.	
8:00 A.M.	14,700	22,500	88,000	37,200	40,600
10:00 A.M.	33,500	53,400	153,200	61,300	75,400
1:00 P.M.	50,300	66,600	195,800	97,800	102,600
3:00 P.M.	49,200	62,200	167,800	76,000	88,800
3:00 A.M.	18,400	23,900	131,000	39,900	53,300
Average	33,300	46,400	147,100	63,400	72,600

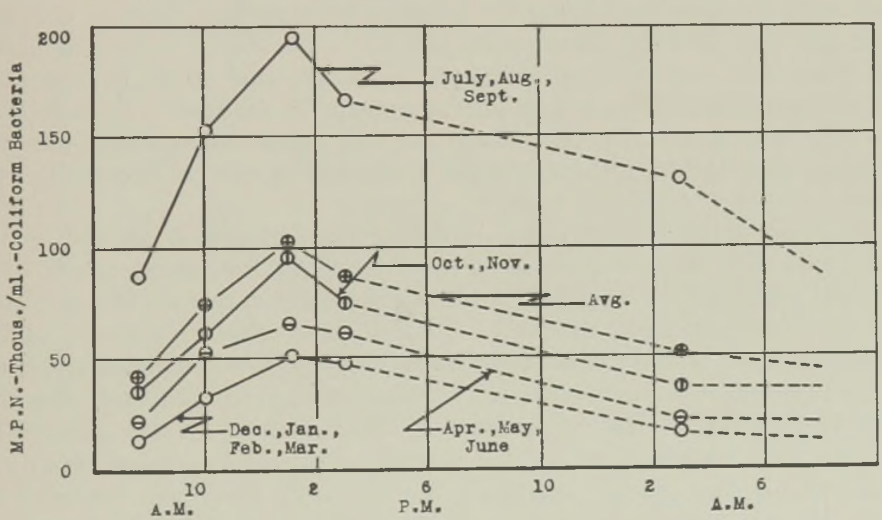

FIG. 2. Variations during a 24 hour period in coliform content of raw sewage by seasons, data for period Sept., 1938, to Mar., 1941, inclusive.

It appears from a study of the original daily data that during storm flows, the concentration per ml. of bateria is very little different than during normal dry weather flows, except that the total count is usually somewhat more. This same situation exists for the chlorine demand (5) where, although the total demand in pounds increases with the flow, the concentration does not increase greatly with storm flow, except during the first hour of the storm. It also appears that industrial wastes, which affect the chlorine demand considerably, have little or no effect on the coliform content of the raw sewage.

Operating Results

In order to appreciate fully the effectiveness of disinfection of Buffalo sewage, it is necessary to tabulate the average bacterial results, along with data on chlorination for the same five hours represented by the average bacterial data. This has been done in Table IV. It should be emphasized that data in this table represent the monthly averages for the five hours at which samples are taken. For comparison, the 24-hour average flow and chlorination data for the same 31 months are included. From this comparison it is readily observed that the data for these five hours each day are very nearly the 24-hour average, thus confirming the choice of these particular hours. The contact time listed in Table IV represents one-half of the theoretical detention period of the particular flows shown. The use of this value for the flow through or contact time appears to be reasonable (10).

Attention is called to the column headed "Per Cent Satisfaction." This value is calculated from the relation between the chlorine demand in lb. per day, and the chlorine dosage in lb. per day. It will be noted that the demand satisfaction is less than 100 per cent in the cold months and greater than 100 per cent during the warm months. As indicated in a previous paper (1), the reason for this apparent anomaly has not yet been ascertained although studies are under way to determine the cause.

In considering this relation of dosage to demand, it should be remembered that dosage control is predicated on the maintenance of a residual of 0.1 p.p.m. 15 minutes after chlorination, not on the satisfaction of the determined demand. Therefore, if this residual is maintained, then the actual demand (by definition) (1, 6, 8) has been satisfied. Partial satisfaction is measured by any amount of chlorine demand existing 15 minutes after chlorination. In this way a truer picture of the per cent satisfaction of the chlorine demand has been obtained. These values for the per cent satisfaction have also been included in Table IV. It appears that it is not essential to maintain 100 per cent satisfaction even on this basis in order to produce satisfactory disinfection under the conditions of contact time available. Inspection of the data in Table IV indicate this to be true.

The bacterial data (Table IV) show that the residual coliform bacteria in the plant effluent averaged approximately 1000 per ml. This value which has been set as desirable, was exceeded appreciably in seven months during the study. Results in these seven months were not ex-

TABLE IV.—*Operating Results by Months. Avg. Data for Five Hours Each Day*

Month	Flow M.G.D.	Temp. °F.	Chlorination					Bacterial Results					
								M.P.N. Coliform per ml.			Total Count		
			C.D., lb./day	Chlorine Dosage, lb./day	Contact Time, Min.	Per Cent Satisfaction Dosage/Demand	Per Cent Satisfaction Based on Resid. at 15 Min. Contact	Raw Sewage	Effluent	Per Cent Removal	Raw Sewage	Effluent	Per Cent Removal
1938													
Sept.	114.	71.0	5610	5850	53	104.1		216,200	650	99.6	1,774,500	25,600	98.5
Oct.	103.	65.0	6450	4820	58	74.7		88,100	1660	98.2	1,292,600	25,500	97.8
Nov.	123.	57.5	7480	6180	49	82.6		74,300	1280	98.4	861,000	28,500	97.6
Dec.	136.	50.2	7800	6370	44	81.6		37,900	140	99.5	215,000	960	99.5
1939													
Jan.	130.	47.3	5280	4950	46	93.8		40,100	20	99.9	—	—	—
Feb.	157.	45.2	5890	4230	38	71.9		15,400	250	98.3	86,800	1,860	97.7
Mar.	157.	45.8	5340	4590	38	85.9		16,100	460	96.5	109,400	3,200	97.0
Apr.	151.	47.9	5050	3640	40	72.1		36,400	2230	93.6	112,100	6,450	94.1
May	127.	56.3	5260	5080	47	96.6		53,100	880	98.2	187,000	9,630	94.7
June	109.	66.1	6130	5320	55	86.6		84,000	620	97.26	271,200	22,200	91.83
July	127.	72.0	7550	7710	47	102.1		191,400	1000	99.48	484,600	7,660	98.40
Aug.	127.	74.7	6590	6920	47	105.0		163,600	920	99.44	2,020,000	30,800	98.48
Sept.	136.	70.8	7780	8270	44	106.2		141,800	3960	97.21	1,454,000	36,100	97.52
Oct.	132.	65.4	7000	7870	45	112.2		75,400	1530	97.97	—	—	—
Nov.	120.	58.8	6220	7520	50	120.8	100	54,700	50	99.91	—	—	—
Dec.	131.	52.8	6420	5600	46	87.3	95.5	50,000	290	99.42	—	—	—

TABLE IV.—*Operating Results by Months. Avg. Data for Five Hours Each Day—Continued.*

Month	Flow M.G.D.	Temp. ° F.	Chlorination					Bacterial Results					
			C.D., lb./day	Chlorine Dosage, lb./day	Contact Time, Min.	Per Cent Satisfaction Dosage/Demand	Per Cent Satisfaction Based on Resid. at 15 Min. Contact	M.P.N. Coliform per ml.			Total Count		
								Raw Sewage	Effluent	Per Cent Removal	Raw Sewage	Effluent	Per Cent Removal
1940													
Jan.	131.	48.7	5940	4610	46	77.7	94.2	48,800	260	99.47	—	—	—
Feb.	140.	46.7	5490	4040	43	73.6	88.1	38,000	1720	98.22	—	—	—
Mar.	180.	45.4	6340	3540	33	55.9	86.2	24,700	1240	95.10	—	—	—
Apr.	172.	48.5	5160	3300	35	63.9	81.2	29,800	3350	88.76	—	—	—
May	132.	54.8	4990	3830	45	76.8	92.1	36,800	600	98.36	—	—	—
June	134.	64.2	6050	6630	45	109.8	99.7	59,800	1100	98.16	—	—	—
July	123.	69.5	6190	7220	49	116.4	94.3	108,400	200	99.82	—	—	—
Aug.	130.	72.5	6530	7460	46	114.1	94.1	119,600	1310	98.91	—	—	—
Sept.	127.	68.5	6840	7470	47	109.1	94.6	118,800	1740	98.54	—	—	—
Oct.	120.	64.2	6680	7310	50	109.3	97.6	64,400	170	99.74	—	—	—
Nov.	157.	55.9	8140	7280	38	89.5	91.8	34,100	530	98.44	—	—	—
Dec.	206.	49.2	9520	6500	29	68.3	82.0	26,800	1400	94.78	—	—	—
1941													
Jan.	139.	48.8	6760	5470	43	80.8	94.3	28,800	690	97.59	—	—	—
Feb.	138.	47.6	7310	5310	44	72.6	93.8	29,000	670	97.68	—	—	—
Mar.	162.	46.3	7470	5270	37	70.5	96.5	28,800	1450	94.96	—	—	—
5 Hr. Avg.	138.	58.0	6500	5800	44	89.3	92.7	75,100	1040	98.6	840,000	16,600	97.9
24 Hr. Avg.	136.		6950	5710	44	82.3	91.7						

ceptionally high and usually occurred when the average flow was high. During ten months the average coliform content of the effluent was considerably below the 1000 per ml. average. Although the per cent kill or reduction of bacteria is of less importance than the number of bacteria discharged from the plant, it is gratifying to note that the per cent kill has averaged 98.6 per cent. Thus the coliform bacteria have been reduced from an average of 75,000 per ml. to 1000 per ml.

It will also be observed from Table IV that the results for twelve months indicate that the total bacteria in the raw sewage were reduced from 840,000 per ml. to 16,600 per ml. for an average kill of 97.7 per cent. In view of the fact that the total bacteria are not of particular sanitary significance and the kill of these bacteria is approximately of the same order as that of coliform bacteria, the determination of total bacteria on agar was discontinued from the routine after twelve months.

Some consideration should be given to the data which indicate effluent contents of coliform above 1000 per ml. As indicated above, these higher values are considered as due to storm flows. From the description of the plant operating procedure and the method of chlorine dosage control used during storm flows (1), it is understood that complete chlorination is not used at such times. To ascertain the effect of storm flow data on the average coliform content, tabulations and averages of the data have been made comparing the all flow averages with the averages for dry weather flows. These comparisons are listed in Table V.

A study of the daily plant data shows that the dry-weather flow average has been 113 m.g.d. and the all-weather average 136 m.g.d. to date. Therefore those data in Table V for flows less than the dry-weather average indicate extremely dry weather and those data for flows greater than the all-weather average indicate considerable excess storm flow. With this observation in mind, it appears that quite generally during the months of high flows, the content of coliform bacteria in the plant effluent is higher due to these storm conditions. For the entire period, it appears that the dry-weather average is approximately half of the all-weather average, and well below the desired limit of 1000 coliform per ml. On the basis that flows of more than 150 m.g.d. exist approximately 30 per cent of the time, it may be estimated that during these flows the coliform content of the plant effluent averages approximately 2200 per ml.

Accomplishments of Sewage Disinfection

In considering all of these bacterial data, one may ask, "What has been the effect of the plant operation on the pollution of the Niagara River?" Monthly surveys of the river have been continued and additional data since the last published report (4) are now available. All the data available on the coliform content of the Niagara River are shown in Table VI. Studies in 1936 (3) showed that the sewage from Buffalo was almost never dispersed in more than 30 per cent of the flow of the Niagara River and remained within a relative boundary line in the American Channel. Therefore, sampling schedules and locations were limited to the pollution zone and in the past two years samples have been taken only from the two bridges over the American Channel to Grand Island. The upper bridge (Series EE) is located 5.8 miles below the plant effluent outlet and the lower bridge (Series H) is 15.7 miles below the effluent outlet.

TABLE V.—*Effluent Coliform Content Including and Excluding Storm Data*

Month	Flow, M.G.D.	M.P.N. Coliform per ml.	
		Average Including Storm Flows	Dry Weather Average
1938			
Sept.	114.	650	650
Oct.	103.	1660	1660
Nov.	123.	1280	1280
Dec.	136.	140	140
1939			
Jan.	130.	20	20
Feb.	157.	250	60
Mar.	157.	460	480
Apr.	151.	2330	2140
May	127.	880	890
June	109.	620	540
July	127.	1000	740
Aug.	127.	920	850
Sept.	136.	3960	3590
Oct.	132.	1530	370
Nov.	120.	50	13
Dec.	131.	290	140
1940			
Jan.	131.	260	90
Feb.	140.	1720	140
Mar.	180.	1240	240
Apr.	172.	3350	360
May	132.	600	450
June	134.	1100	350
July	123.	200	110
Aug.	130.	1310	150
Sept.	127.	1740	730
Oct.	120.	170	90
Nov.	157.	530	10
Dec.	206.	1400	140
1941			
Jan.	139.	690	340
Feb.	138.	670	450
Mar.	162.	1450	430
Average	138.	1040	540

Table VI shows the average coliform content at the two stations before sewage treatment was inaugurated, the average content from September, 1938, to May, 1940, inclusive, and the monthly data for June, 1940, to May, 1941, inclusive. At the upper bridge the average content of 7.1 per ml. since sewage treatment began indicates a reduction in pollution of 97.8 per cent over conditions existing prior to July, 1938. At the lower bridge the reduction of 87.9 per cent to 16.1 per ml. shows the effect of pollution of other cities below Buffalo.

TABLE VI.—*Cross Section Average (Pollution Zone) of Coliform Bacteria in the Niagara River Below Buffalo*

Results in M.P.N. per ml.

Months	Sampling Stations Series EE	Series H
Miles Below Buffalo Outlet	5.8	15.7
Flow Time Below Buffalo Outlet	3 hrs. 30 min.	11 hrs. 30 min.
Avg. 6/36 to 8/38*	323	134
Avg. 9/38 to 5/40*	11.2	16.3
June, 1940	5.9	31.7
July	2.3	24.8
Aug.	8.0	13.0
Sept.	14.7	13.1
Oct.	4.3	9.8
Nov.	24.5	32.0
Dec.	11.6	33.5
Jan., 1941	0.7	6.4
Feb.	1.2	2.6
Mar.	4.3	16.5
Apr.	4.5	5.6
May	3.3	4.8
Avg. 6/36 to 8/38	323	134
Avg. 9/38 to 5/41	7.1	16.1
Per Cent Reduction	97.8	87.9

* Reference 4.

It is not possible to correct these data for the coliform content of the Niagara River before it reaches the sewage treatment plant because cross-sectional samples of the river at that point are not available. On the other hand, samples taken near the shore above the treatment works outlet have shown coliform contents of 4 to 93 per ml. Thus not all of the bacterial content of the Niagara River can be attributed to the Buffalo sewage treatment works.

Without discounting this normal river bacterial content, some consideration can be given to the relation between the bacteria discharged from the treatment works and those found in the river, assuming that the samples of the river represent normal and average conditions. Data from the U. S. Lake Level Survey (11) when converted to volume show the average flow to have been 189,000 c.f.s. during the period of study.

Previous studies (3) indicated the sewage to be dispersed in only 30 per cent of this flow or in 56,700 c.f.s. The 31 month average (September, 1938, to March, 1941, inclusive) flow of sewage was 210 c.f.s. Under these conditions the dilution of Buffalo's treated sewage was 1 to 270. At this dilution, the average coliform content of the river should have been 3.8 per ml. whereas the average was 7.1 per ml. In part, the difference is undoubtedly due to the normal content of the river. Some of the difference may be due to re-growth cycles, although laboratory experiments (2) indicated that there was little tendency toward re-growth in chlorinated effluents when highly diluted.

Although the average coliform content of the pollution zone of the river below Buffalo has been 7.1 per ml., the annual average cross-section content, on the basis of the total flow in the river, is only 2.4 per ml., which is below the limit of 5 per ml. set by the International Joint Commission on Pollution of Boundary Waters Reference (12). From these observations, it must be concluded that the Buffalo Sewage Treatment Works is accomplishing its desired object.

Fundamental Implications of the Data

Because plant operation data may be influenced by empirical relations, it is not often possible to establish fundamental principles from such observations. On the other hand, statistical studies of such data do frequently imply certain fundamental relationships which may point the way to laboratory experimentation, for proof. The data in this paper, in addition to recording the results of plant operation show certain indications as to principles of disinfection of sewage by chlorination.

Figure 3 shows the data on contact time, per cent kill, effluent content, and per cent satisfaction of chlorine demand as determined from the demand-dosage relation. In regard to the per cent satisfaction, it appears that there is no direct relation between satisfaction and kill, for the per cent kill is practically constant in spite of the variation in the dosage demand relation. These data on per cent satisfaction as shown in Fig. 3, indicate some seasonal factor in the determination of the demand. Previous studies (6, 7) have indicated that this factor cannot be a slight temperature or time variation between the sewage in the conduit and the sample in the laboratory. Studies on this factor are continuing.

One important indication of these curves is that when a residual of 0.1 p.p.m. is maintained for 15 minutes contact, or the demand appreciably reduced in that time, then any contact time of 30 minutes or more will produce satisfactory coliform reductions to approximately 1000 per ml. or less. Otherwise there is no definite relation between contact time and per cent kill or residual content of coliform. Likewise temperature apparently has no relation to kill so long as residual and contact time are sufficient. The apparent decrease in contact time and in the per cent satisfaction (as measured by the dosage-demand ratio) in winter and spring months is due to high flows, not temperature.

Although no data are listed for chlorine demand in p.p.m., it appears from consideration of the data published heretofore (5) that there is no relation between chlorine demand and number of bacteria. It is true that both increase similarly during the day and vary similarly by seasons, but these data show no reason to disagree with Rudolfs and Gehm (9) that bacteria themselves exert no appreciable chlorine demand.

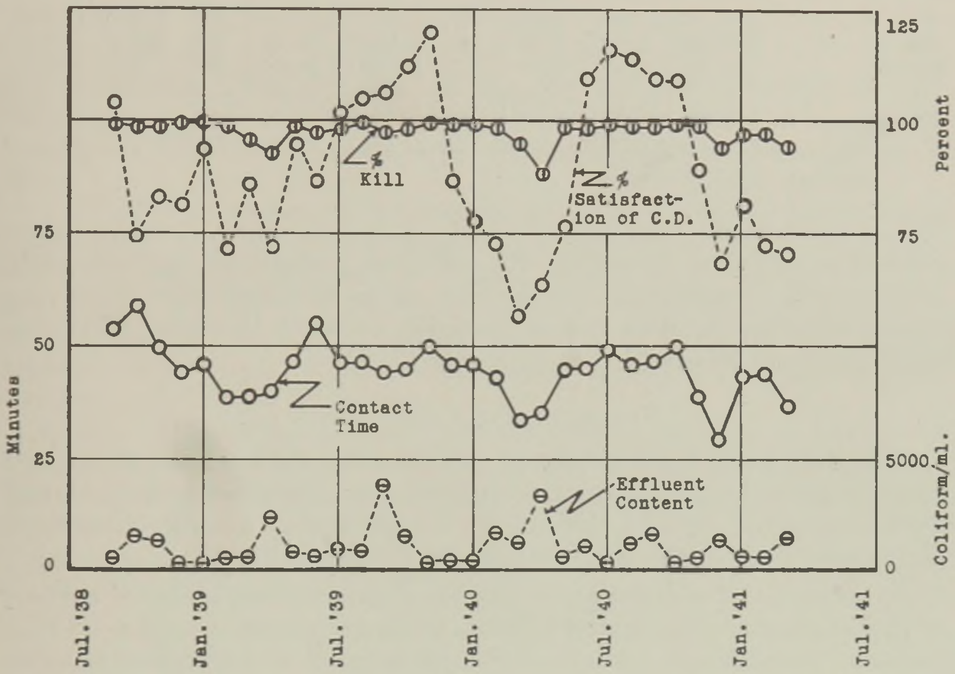

FIG. 3. Monthly data on per cent satisfaction of chlorine demand, contact time and per cent kill of coliform.

Rather, these similar trends appear to be independent measures of strength of sewage. Quite probably the increased growth of bacteria in warm sewage contributes to higher chlorine demand, not because of themselves but because of organic split products which they produce in greater amounts due to greater numbers and more rapid activity.

As a check on the effect of contact time certain additional sampling and analyses were performed. Samples taken of the tank influent one minute after chlorination were allowed to stand an additional 14 minutes after which thiosulfate was added and the sample cultured. These experiments were carried on at three different hours during the day for six months (three months in cold weather and three months during warm weather). Results of these experiments indicate therefore the effect of disinfection with 15-minute contact and when compared to the plant results for the same hours in Table VII, the effectiveness of contact time is observable. The data show that, regardless of tempera-

Table VII.—*Effect of Contact Time on Per Cent Reduction of Coliform in Sewage*

Month	Coliform per ml. Raw Sewage	Avg. of 3 Tank Influent Samples*		Min. Flow Through Time	Avg. of 3 Plant Effluent Samples		Difference		Per Cent Increase Removal
		Coli/ml.	Per Cent Removal		Coli/ml.	Per Cent Removal	Coli/ml.	Per Cent Removal	
Dec. '39	69,000	260	99.58	46	190	99.69	70	0.11	0.10
Jan. '40	59,600	400	99.28	44	360	99.42	40	0.14	0.07
Feb. '40	50,300	1,620	96.78	40	1,150	97.84	470	1.06	0.93
July, '40	111,200	350	99.70	46	240	99.79	110	0.09	0.10
Aug. '40	138,900	1,640	98.93	46	1,340	99.06	300	0.13	0.22
Sept. '40	144,500	2,140	98.71	47	1,860	98.88	280	0.17	0.19
Average	95,600	1,070	98.83	45	860	99.11	210	0.28	0.27

* 15 minutes after chlorination.

ture, a residual chlorine content of 0.1 p.p.m. in sewage after 15 minutes contact is sufficient to reduce the coliform content to approximately 1000 per ml. Additional contact time up to 40–45 minutes while providing a safeguard does not appreciably increase the kill. This confirms previous laboratory experiments (2, 9).

Summary and Conclusions

The following brief summary outlines the main observations and conclusions to be drawn from a study of the laboratory and treatment works operating data at Buffalo for a period of 31 months after complete control of sewage chlorination was established.

1. Analysis of refrigerated composite samples for bacterial content of raw sewage or chlorinated effluents gives erroneous results as to true bacterial populations. Analyses should be made on individual samples as frequently as possible and soon after sampling. Chlorinated samples should be treated with thiosulfate.

2. By considerations of the hourly variations in the concentration or strength of sewage as represented by chlorine demand, it is possible to choose five or six hours during the day for which the average data will approximate the average for the entire 24 hours and therefore present a relatively accurate picture of plant operation disinfection results for the entire day, provided of course, that chlorine dosage control averages the same during the entire day as at the several chosen hours.

3. The bacterial population and coliform content of raw sewage varies as the temperature of the sewage, and varies during the day directly with the strength of sewage.

4. Results based on plant operating data indicate that maintenance of a 0.1 p.p.m. residual chlorine content or nearly so at 15 minutes, when the total contact time is 30 to 45 minutes, reduces the coliform content of the sewage to approximately 1000 per ml. for a kill of 98.6 per cent, regardless of the temperature of the sewage.

Similar results as regards per cent kill are obtained for the total bacteria (on agar at 37° C.). Total bacteria are approximately eleven times the coliform content of the raw sewage and sixteen times that of the chlorinated effluent.

5. Tests on chlorinated raw sewage fifteen minutes after chlorination, when compared to the plant effluent, indicate that little additional kill is gained on additional contact, provided a residual of 0.1 p.p.m. exists at fifteen minutes.

6. Storm flows have little effect on the concentration of bacteria in raw sewage. On the other hand, because only partial chlorination is employed during storms, the effluent content is greater under storm flow conditions. Whereas dry weather averages for the coliform content are about half the limit set by the laboratory of 1000 per ml., during storms the effluent content of coliform is slightly over two times that limit.

7. The effectiveness of the method of control devised in the Bird Island Laboratory (1), *i.e.*, maintenance of a 0.1 p.p.m. residual fifteen minutes after chlorination, with hourly adjustment of dosage based on the demand and flow, is proved by the bacterial data, which show a reduction of bacteria to approximately 1000 per ml. (except during storms) regardless of temperature, chlorine demand, original bacterial content, and strength of sewage.

8. The effectiveness of disinfection and its method of control is further attested by stream pollution studies which show that since the inception of sewage treatment at Buffalo, the coliform content of the Niagara River has been reduced by approximately 98 per cent, and the concentration of coliform below Buffalo now meets the standards of the International Boundary Commission.

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PRINCIPLES AND FACTORS INFLUENCING VACUUM FILTRATION OF SLUDGE *

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Influence of Gravity in Dewatering Sewage Solids.—Although vacuum filtration of sludge is a dewatering process, the minute sewage arrives at a modern treatment plant we start dewatering mineral and organic solids. We are accustomed to regard plain sedimentation as a means of collecting suspended settleable solids. In realty it does about 300 to 350 times more dewatering than is done in the vacuum filters handling the sludge from plain sedimentation and digestion.

According to Imhoff and Fair, "Sewage Treatment," domestic sewage in this country contains 180 p.p.m. settleable solids and 999,200 p.p.m. pure water. If gravity settling produces a plain sedimentation sludge of 95 per cent water and 5 per cent solids and vacuum filtration of this sludge produces a filter cake of 25 per cent solids and 75 per cent water, the following amounts of dewatering per pound of settleable solids result:

Sewage contains approx.	5550 lb. water/lb. solids	
Primary sludge contains	19 lb. water/lb. solids	
Plain sedimentation removes	5531 lb. water/lb. solids	or 99.66% of total
Primary sludge contains	19 lb. water/lb. solids	
Filter cake contains	3 lb. water/lb. solids	
Filtration removes	16 lb. water/lb. solids	or 0.29% of total
Leaving for evaporation abt.	3 lb. water/lb. solids	or 0.05% of total

Further concentration of the solids by gravity thickening may increase the proportion of gravity work done to about 99.77 per cent. By digesting the plain sedimentation sludge and spreading it on sand beds we may use gravity and air drying to do 96 per cent of the remaining 0.23 per cent of dewatering to be done.

Complete drying can be accomplished only by evaporation. However, when sedimentation will do about 99.66 per cent of the dewatering for us, it is readily seen why sewage treatment practice, like that of other industries (from which it borrowed and adapted most of its mechanical equipment) takes dewatering in stages, *i.e.* plain sedimentation, thickening, sometimes sludge digestion, draining on sand beds or by mechanical filtration and finally evaporation.

This paper relates to about 0.3 per cent of total solids dewatering and leaves about 0.04 per cent of the story to those concerned with heat drying and incineration. The instant we take over the job where gravity can no longer work rapidly enough for us, the more stir we make and the more money we spend. In other words, the smaller the frac-

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tion of water to be removed becomes, the greater becomes the expenditure per pound of water and the more we talk about it.

Basic Principles

The Influence of Specific Gravity on Dewatering.—This 99.66 per cent of the dewatering done by plain sedimentation in sewage treatment is accomplished with solids having a specific gravity of about 1.2 and a sludge having a specific gravity of but 1.008. The settleable solids consist of approximately 28 per cent mineral matter, of 2.5 specific gravity, and 72 per cent organic matter of the same density as the water present.

If the settleable solids were all mineral of this specific gravity 2.5, the sludge could contain 50 per cent solids and the filter cake could have 80 per cent solids. In such a case plain sedimentation would produce a sludge of 1.43 specific gravity and do about 99.98 per cent of the total dewatering while the vacuum filter does about 0.014 per cent, leaving for evaporation about 0.006 per cent. Here plain sedimentation does about 7200 times more dewatering per pound of settleable solids than does the vacuum filter.

One cannot intelligently discuss vacuum filtration principles without first discussing the nature of the sludges subjected to filtration. The very factors which influence plain sedimentation also materially influence filtration.

Diminishing Void Volume.—This could very well be the title of my discussion because the accumulative effects of diminishing void volume make it the dominant principle in the entire story of sedimentation, draining and forced filtration.

The water present as moisture in sludges and their filter cakes occupies the space voids between the solid particles and is therefore a direct measure of the void volume present. With this fact in mind, sedimentation, thickening and filtration are nothing but progressive steps in diminishing the original void volume. The more this void volume dwindles the more powerful its throttling action becomes against gravity and filtration pressures. The structure, specific gravity and relative wetability of solids determine the void fractions left in settled and filtered sludges.

In plain sedimentation we attempt to hold the water relatively quiescent and allow gravity to pull the settleable solids down through the water. In the free settling zone of such tanks the solids stagger freely downward at various constant rates determined by their size, shape, density and the laws of free falling bodies. The tank bottom prevents continued movement of the solids so at some liquid depth they start crowding into the void volume sufficiently to interfere with each other's fall. At this transition stage the settling rate decreases. Impeded settling then follows wherein both settling and a crude form of upward liquid filtration occur. As the consolidating solid aggregates settle farther they displace water upward through the existing void channels thereby materially diminishing the void volume. The solids and water move in opposed directions with the water containing some fine, suspended solids doing the staggering. The law of capillary flow in the diminishing voids now opposes the law of gravity. When, during the allowed detention period, the void volume has diminished to the extent where the flow throttling action of the void channels equals the effect of gravity, gravity can do no more for us in plain sedimentation.

In thickening by gravity, slow moving stirrers and sludge collectors are frequently effective in further consolidating the solids so more water can be displaced upwards through new void channels made in the sludge. However, as in plain sedimentation, the void volume finally remaining in the sludge is a function of the specific gravity of the solids, their surface attraction for water and, to some extent, the depth of the sludge blanket.

Draining on sand beds is also a crude form of filtration. Here we reverse the solid sedimentation process, namely, spread the thickened sludge on a supporting bed of porous sand with proper underdrains and let gravity pull the water through the decreasing void fraction of the sludge and the relatively constant void channels of the sand bed. Ultimately the pronounced capillary resistance of the void channels in the sludge throttles all filtrate flow.

Some residual water always remains in the capillary voids of the drained sludge and the volume and weight of the water thus retained per unit volume or weight of solids depends primarily on the same factors that control sedimentation. The finer the solid particles are and the more surface attraction they have for water, *i.e.* the more hydrated and compressible their aggregate structure is, the greater will be the number of capillary void channels and total void volume after settling and the lower will be the specific gravity of the sludge related to the water or dilute solution in which the sludge has settled. If the solids have a low specific gravity, this effect is augmented.

Low specific gravity and high surface attraction for water are characteristic of sewage solids. The same is true of typical hydrated solid precipitates of metal hydroxides in water. Powdered dry precipitates of aluminum and ferric hydroxide have relatively high specific gravities, *i.e.* respectively about 2 and 3 times that of wet sewage solids. However, the highly wet (hydrated) voluminous precipitates of these hydroxides in water alone or flocculated with sewage solids contain so much moisture (void volume) that their specific gravity is greatly diminished. This hydration factor and its associated high void volume factor directly influence the important other factors operating in the sedimentation and draining or filtration of all sludges.

The smaller the percentage of void volume (void fraction) left in a sludge by sedimentation, the easier is filtration. Some metallurgical sludges of high specific gravity represent the easy end and sewage sludges with their highly hydrated solid aggregates and precipitates of low specific gravity represent the difficult end. Naturally there are different degrees of void volume with corresponding ease and increasing difficulties in between these two ends.

Metallurgical slimes (sludges) containing fine mineral solids of relatively high specific gravity sometimes contain 70 per cent solids after sedimentation thickening and yield vacuum filter cakes of 90 per cent solids. This is quite the reverse of results on sewage sludges, wherein sludge and filter cake moisture percentages completely switch places with the solid percentages in the exemplified metallurgical filter cake and sludge, *i.e.* some digested sludges may have as low as 90 per cent moisture and the vacuum filter cakes 70 per cent moisture.

Time, Space and the Filter.—We use mechanical filters of various kinds to hasten the action of gravity in sludge dewatering thereby reducing the relatively large space required for gravity draining and air drying.

In hydraulically forced filtration we use driving forces on the water greater than gravity to speed up the dewatering process. For example, hydraulically forced filtration through one square foot of modern continuous vacuum filter area is capable of draining the water from digested sludge about 2,000 times faster than is normally accomplished by gravity and air drying over a square foot of open sand bed area. This time element, or rate factor, is of primary importance in the principles with which we are concerned.

It should be emphasized here, however, that hydraulically forced pressure (another important factor) is by no means the sole factor in multiplying the effect of gravity draining some 2,000 times. Even with the factor of relatively thin cakes common to vacuum filters, if we don't employ some means to offset and delay the accumulating, powerful rate throttling effect of diminishing void volume in the accumulating filter cakes we rapidly encounter economic defeat. As will be shown, we do this by chemical coagulation of the sludge solids.

Filter Medium.—Every filter begins with a permeable or porous support for the solids. This support is relatively permanent and in filtration literature is termed the filter base, septum or filter medium. Actually the filter medium for the entire filtration process is composed of this supporting filter base and the cake of solid material collected on it. The filter base, according to usage and purpose, may be a bed of sand used in a horizontal position only, or in our modern vacuum filters, a properly supported cloth made of metal, cotton duck, flannel, wool or other relatively durable but strong material. It naturally offers some resistance to filtration and this resistance materially increases with use.

After a short period of time, the cake of accumulating sludge solids becomes the actual filter medium. As new solids are deposited in the cake its diminishing voids and growing structure offers more resistance to filtrate flow.

General Filtration Principles and Factors

Next year it will be 100 years since the French anatomist, Poiseuille, published his classic equation for the flow of fluids under pressure through capillary tubes (1). In its following simple form this equation contains the essential framework for our more recently evolved filtration equations:

$$V = \frac{\pi P r^4}{8Lu} = \frac{0.3927 P r^4}{Lu},$$

where "V" is flow velocity, "P" is pressure difference at tube ends, "r" is internal capillary radius, "L" is the length of opening and "u" is the viscosity of the fluid. Of prime interest here is the powerful effect of decreasing or increasing the radius of the opening, *e.g.* by reducing it to ⅛th its size we must increase the pressure over 4,000 times to get the same flow rate at the same tube length and viscosity. Conversely doubling the radius produces 16 times as much flow with other factors constant.

Darcy (1856), Hazen (1892), King and Slichter (1897) proved this equation true for flow of water through sand, earth and other similar porous mediums. Later scientific investigators assumed and proved the same was true for filtration rates through filter cakes of various mineral materials at various cake thicknesses. The obvious relationship between cake thickness and length of capillary channels formed by the voids between solid particles and the number of capillaries per unit filter area became evident in such investigations. As these investigators were chiefly concerned with suspensions of solids in water and the viscosity of water is dependent on temperature, this factor was introduced.

Hatschek 33 years ago (2) showed experimentally that resistance to filtration increases most rapidly with diminishing sizes of the particles deposited in the cake. Young, 30 years ago (3), confirmed these conclusions for the vacuum filtration of fine silica and clay slimes. At about the same time Almy and Lewis (4) published the first empirical equation for filtration. This was subsequently modified by the authors. Then in 1916 and 1917 Sperry (5) starting with the Poiseuille equation, theoretically and empirically evolved his rather formidable appearing equation. This equation included, among numerous factors, the factor for the resistance of the filter base. Other investigators debated and modified this equation. It was the first attempt at complete mathematical treatment of the subject and was fairly reliable for incompressible sludges and filter cakes, *i.e.* having constant void volume under pressure like that existing in a cake or bed of clean sand. Finally Ruth and his co-workers (6) concluded that any variations in the average permeability of a filter cake during filtration is entirely due to variations in void volume throughout the cake and they ingeniously use the relationship between void volume and permeability under pressure for deriving their equations. These equations therefore include factors for compressibility of the cake during filtration and filter base resistance. Evidently they are difficult to apply to sludges having excessive compressibility like those encountered in sewage sludge filtration. However, they are of considerable value in this discussion if we remember:

(1) That the differential rate of filtrate flow at any time during filtration is directly proportional to the pressure producing it, divided by the resistance encountered. This is nothing but a simplified expression of the capillary flow equation notwithstanding the numerous factors expressing this resistance. Pressure produces filtrate flow simultaneous with solid packing into the cake. The growing solid deposit and packing lengthen the void channels and diminish their size which throttle further flow. This throttling action is what we term cake resistance and like filtration pressure has specific values.

(2) In reality the various factors of these equations in some way measure the physical properties of the solids involved. If we understand these properties we can maintain sludge and filter conditions which influence economic optimal yields providing the filter itself is properly constructed, installed and operated. Rather than attempt to discuss the mathematical relationship of these fundamental factors I will list and describe the properties which they measure.

General Factors (Mathematically Related)

1. Effective filter area.
2. Filtration pressure (pressure difference on two sides of septum).
3. Nature of solids (density, particle size, compressibility).
4. Water or solution present in sludge and filter cake and its density.
5. Rate of solids deposit in filter cake (from filtrate flow rate).
6. Resistance of filter base (cloth) to filtrate flow.
7. Resistance of filter cake to filtrate flow.
8. Time by which rate factors are measured.
9. Coefficient of viscosity of filtrate or sludge moisture.
10. Temperature.

Through the construction and operation of mechanically operated filtration equipment the engineer aims to take advantage of these factors. This introduces some new, purely economic factors relating to the construction, installation and operation of the continuous vacuum filter itself and its accessory equipment.

Van Kleeck (7), Keefer (8) and others have ably described the vacuum filter equipment and its practical application to sludge filtration. Briefly it is a rotating drum equipped with a filter base and so constructed that under mechanically produced suction it can rapidly and continuously pick up a thickened deposit of solids and drain from this deposit all but a minimum of residual moisture; then, under reversed pressure or by other means, periodically discharge a compacted, relatively dry cake. This is accomplished by submerging the drum with multiple peripheral suction chambers and filter cloth supporting leads in a constantly replenished sludge bath and slowly rotating the drum. The drained cake is then removed from the drum after the suction is automatically cut off. The factors relating to the construction and installation of this filter are missing from the references pertaining to general filtration principles and are therefore added here.

11. Proper installation of filter and all accessory equipment.
12. Security against leakage between drum compartments and in entire suction system.
13. Diameter of filter drum.
14. Number of suction compartments in drum surface.
15. Fraction of total compartments in use for cake forming and drying.
16. Fraction of total compartments submerged in sludge.
17. Fraction of total compartments collecting cake under submergence.
18. Kind and condition of filter cloth (its resistance to flow).
19. Method of supporting filter cloth (its resistance to flow).
20. Effectiveness of draining filtrate from drum compartments, leads and revolving piping without creating flow resistance.
21. Distribution of inflowing sludge freely throughout sludge bath.
22. Drum speed in minutes per revolution or revolutions per hour. This is factor 5 related to factors 3, 4, 6, 8, 15, 17 and 24.
23. Method of removing cake.
24. Minimum cake thickness which can be completely removed from drum.
25. Uniformity conditions conducive to continuous operation. There are several of these.

Here are about two dozen factors with others of importance included in the last; for the filtration of sewage sludges there are a few more of definite importance.

(1) *Effective Filter Area.*—Filtration rates and yields are proportional to the square feet of available and effective filter area. This factor is related to a number of other factors, *e.g.* 12, 14, 15, 16, 17, 19, 20 and the spacing of the wire winding holding the cloth to the drum in filters using wire winding.

(2) *Filtration Pressure.*—This is the hydraulic driving force used for filtration measured in pounds per square inch or other convenient pressure units. As already shown, filtration rates are directly proportional to this force. This pressure is the difference in pressures between the filtrate and cake sides of the filter cloth or base. It is either gravity pressure in sand bed draining and, where gravity is insufficient, some multiple of this pressure obtained by positive pressure pumping or centrifugal force. In vacuum filtration we use a reciprocating air compressor with its inlet ports connected to a tank and piping system, which in turn is connected to the interior of the vacuum filter compartments submerged in the sludge, and the atmosphere exerts its pressure on the sludge. The air exhausted from the submerged and cake covered compartments is then compressed to atmospheric pressure on the exhaust port side of the pump (called dry vacuum pump).

At sea level the available atmospheric pressure is only about 15 lb. per square inch. This is approximately 40 times the 10-in. gravity head of sludge on a sand bed. With good reciprocating vacuum pumps this available pressure is somewhat less. Occasionally, under approximate sea level conditions, some vacuum filters are operated at lower atmospheric pressures, *i.e.* 8 or 10 lb. per sq. in. (16 to 20 in. mercury column). As will be shown, this is erroneous practice.

In vacuum filtration we measure the atmospheric pressure on the suction side of the filter cloth or base by a mercury column indicating the available amount of vacuum in inches mercury, *i.e.* a maximum of about 30 in. at sea level and about 1 in. less for every 1000 ft. increase in altitude above sea level.

For proper filtration the amount of vacuum produced should be as near as economically possible to the local available amount. Furthermore it should be kept constant, *i.e.* free from fluctuations.

(3) *Nature of Solids Present.*—Discussion has already emphasized the prime importance of this factor. It is not alone the fineness of the solids, *i.e.* presence of matter in or bordering on the colloidal state, which determines the rate-throttling effects of the moisture (void fraction) in settled and filtered sludges. The relative compressibility of the solids and solid aggregates can exert the greatest influence on desired filtration results by impeding sedimentation drainage and filtration.

Some solids form relatively porous but rigid cake structures, similar to sand used in water filtration and sludge drying. Such structures are regarded as relatively non-compressible. Under hydraulic pressure they have relatively constant void volumes and capillary channels. Other solids and their aggregates, such as those in sewage sludges, are extremely compressible.

Filtration pressure always stresses the structure of sludge and cake solids. Those solids which are crushed or deformed under this stress are compressible. This means compressibility depends on the solid structure and above all on filtration pressure. During compression the crushed solid aggregates automatically diminish the void spaces through which filtrate must flow. Practically all suspended irregular shaped solids, mineral or other wise, can be deformed by compression when packed in filter cakes. However, sewage solids due to their hydration and irregular shapes are highly compressible. Between the two extremes of sewage and strictly mineral solids there are different degrees of compressibility. Highly compressible sludges, precipitates and their filter cakes are always voluminous, hydrated (have a great surface attraction for water), of low specific gravity, and, under pressure show a rapidly diminishing void volume and high resistance to filtration. Such solids and their complex aggregates, large or small, are also known as capillary porous colloids, having relatively extensive void volumes distributed throughout their minute and larger masses in numerous capillary channels. The visible evidence of their hydration and compressibility is cleavage or cracking of their filter cakes upon drying or draining. This is characteristic of sewage sludges and chemically hydrated precipitates of ferric and aluminum hydroxide.

(4) *Water Present in the Sludge.*—Obviously the nature of the solids greatly influences this factor.

At the beginning of this discussion the pounds of water removed from sewage solids by plain sedimentation were related to the pounds of settleable solids present, and in dewatering sewage sludges we also measure coagulant additions in practically the same terms, *i.e.* pounds of coagulant per 100 pounds of dry sludge solids. By continuing this numerical relationship and measuring the pounds of filtrate drained through a filter cake per pound of cake solids, a very illuminating picture of factors 3, 4, 5, 7 results.

Primarily, the amount of filtrate we get during filtration depends on the amount of water in the sludge and amount of water left in the cake. If we calculate the pounds of water present in both sludge and cake per pound of solids, then the former minus the latter equals the pounds of filtrate produced per pound of solids deposited in the cake. For example if we take six sludge samples, containing 1, 1.92, 3.57, 6.25, 10 and 14.3 per cent solids and measure the samples so each contains but 1 gram of solids, and filter them in a Buechner filter, while

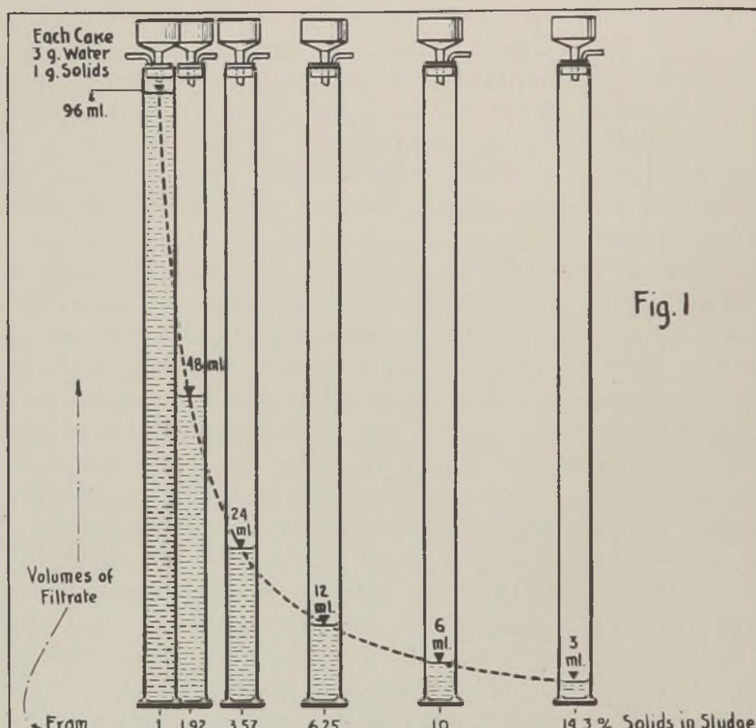


Fig. 1

collecting the filtrate in six successive graduates, we will have six identical filter cakes and cake yields of 1 gram of dry solids with practically identical cake moistures, which are here assumed to be 75 per cent of the total cake weight. The first graduate (See Fig. 1) will contain 96 ml. filtrate and each succeeding graduate will be but one-half of its preceding neighbor. The last will be but $\frac{1}{32}$ the amount collected in the first, namely 3 ml. At the same rate of flow (and pressure) in all instances each successive total sample drains twice as fast as its predecessor and the final sample therefore drains 32 times faster than the first.

The dotted curve drawn through the same point on the liquid level of each graduate includes all the missing samples of sludge having gradual increments of solids. This curve is nothing more than the graph of Fig. 2 showing, in place of grams of solids and filtrate, the pounds of filtrate removed for each pound of solids present in sludges having solid contents ranging from 0.96 to 15 per cent. Doubling the solids content more than halves the amount of filtrate per pound of solids deposited in the cake. For relatively thin sludges the quantities of filtrate passing through the cake and filter base per unit of time are materially greater than is the case with the heavier sludges.

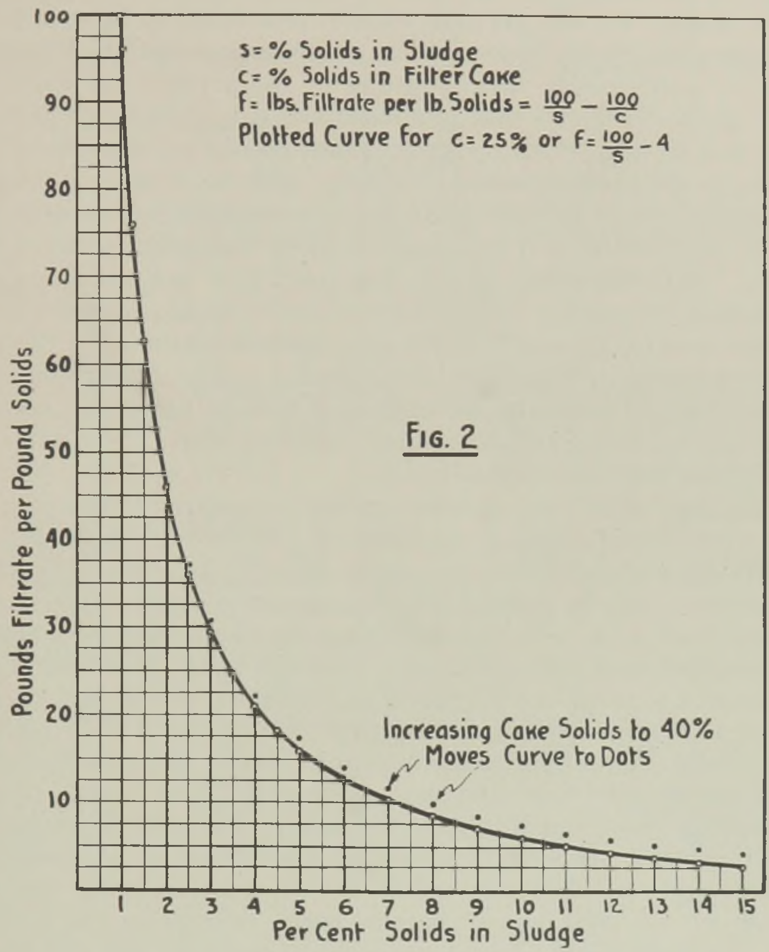


FIG. 2

When we introduce the time element into this picture we are confronted with a most important fact. If we so regulate the filtration pressure on the successive samples that the same amount of solids is deposited on each filter paper per second, it is obvious that the filtration rate per gram of solids deposited, and therefore the velocity of solid deposit or packing (Factor 5), in the thinnest sludge must be double that of its successor and so on until it is 32 times that of the final sample. At high velocities of packing naturally tighter cake deposits result. This velocity of solid packing is a function of filtration pressure (Factor 2) and water present in the sludge (Factor 4) and greatly influences the compressibility of the cake (Factor 3) and the resistance of the cake to filtrate flow (Factor 6). Therefore the compressibility of a filter cake and its resistance to filtrate flow not only results from the action of pressure on the plastic nature of the solids but also from the velocity of packing of these solids, in all states of subdivision, into the cake.

For the same cake thicknesses the throttling action of diminishing voids in a cake, *i.e.* the average specific resistance to filtrate flow, can be increased at least 5 times by low solids concentration, 100 times by fineness of particle size, and 500 times by the presence of compressible solids. Ruth (9) shows that by measuring cake resistance in terms of a given unit of filter cloth resistance, the specific resistance of chemical precipitates of medium compressibility will be increased about 200 times depending on particle size; and the resistance of extremely compressible precipitates will be increased about 10,000 times, depending on pressure. It is therefore logical to expect that low solids concentration, fineness of particle size and compressibility can increase filtration resistance several thousand times over that encountered in dewatering very fine mineral or chemically precipitated solids of low hydration in relatively heavy sludges by filtration. It is to be noted that compressibility of the solids, regardless of their fineness, exerts the greatest effect on filtration rates under pressure.

As the amount of void contraction due to compressibility of a sludge is proportional to the deforming filtration pressure it is logical to expect that filtering a sludge of compressible solids at high pressure and rate will produce a tightly packed cake having several times the flow throttling resistance of a cake obtained from the identical sludge at a much lower pressure and rate. This low pressure head, slow rate filtration is the essence of sand bed filtration, and higher pressure and rapid rate filtration is the essence of forced pressure filtration in a continuous vacuum filter. This filter is a constant pressure and rate filtration device. Consequently thin sludges fed to such filters mean initial high solid packing rates and thin cake formation, while thick sludges mean just the reverse. Obviously when the concentration of solids in the outer layers of any filter cake equals that in the sludge, the filtrate flow rate and rate of solid deposit become zero. Therefore the thicker the sludge, the more these packing rates approach zero and the less their effect.

In the foregoing development of Figs. 1 and 2 the samples of sludge containing increments of solid concentration were purposely chosen to emphasize the above facts and so chosen that each filter cake produced contained but a gram or pound of sludge solids after completion of filtration. This uniform yield of cake solids is the principal purpose behind the development and use of the continuous vacuum filter. We frequently overlook this fact in making Buechner filter tests, *i.e.* in such tests we should aim to get about the same drained cake thickness that can be effectively discharged from the vacuum filter in its normal time for one revolution.

It has already been noted that early investigations of filtration flow rates disclosed the fact that resistance to filtrate flow is also strictly proportional to the amount of new solid material added to the cake as filtration progresses (Factor 7) and this factor can never approach the influence resulting from changing the size of the capillary void channels

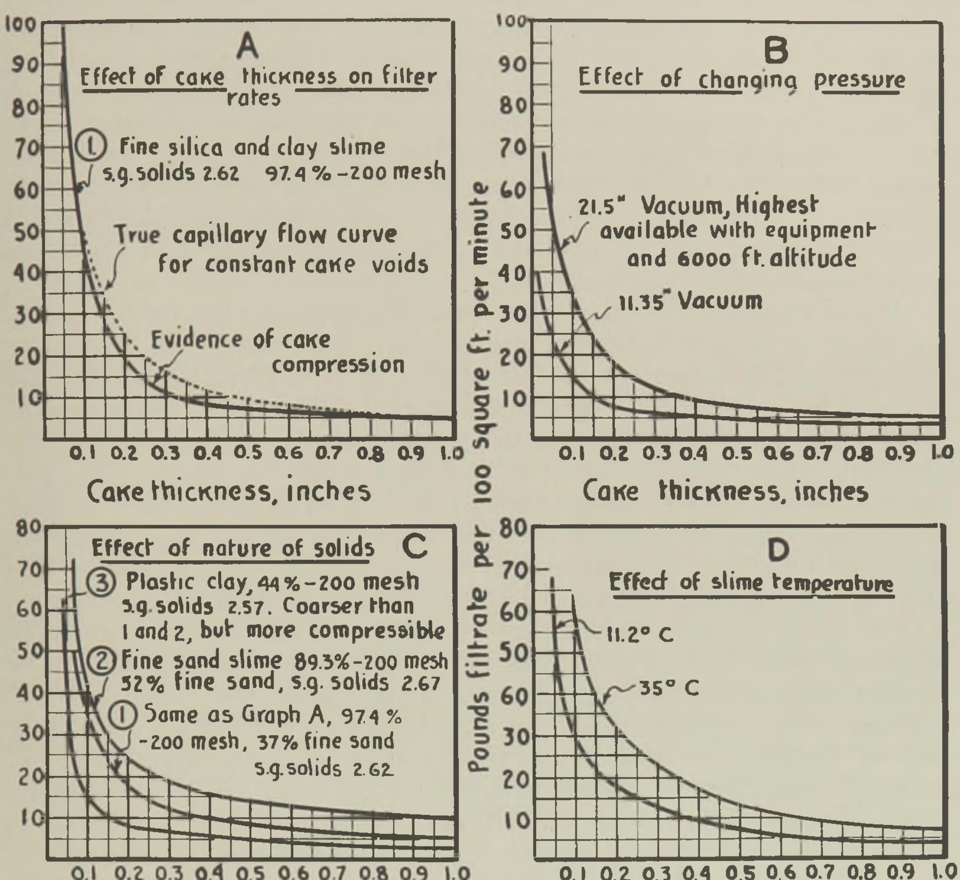


FIG. 3

in a sludge. The effect of increasing cake thickness on filtration rates is evident from Fig. 3.

In Fig. 1 successive cake yields were kept constant, with variations in solid content and sludge volumes. The filtrate yields per pound of cake solids are almost inversely proportional to the solids content of the sludge, *i.e.* doubling the solids content of a sludge almost halves the filtrate per pound of cake solids. However, by keeping the solids content and pressure constant the filtrate flow should vary inversely as the growing cake thickness, *i.e.* doubling the cake thickness halves the flow rate.

This is made evident in the graphs of Fig. 3 where the effect of cake thickness remains when the other capillary equation factors are changed. These graphs are copied from several empirical curves obtained by Professor Young (3) experimenting with a vacuum filter element on fine silica and clay slimes, wherein flow rates are plotted against cake thicknesses in decimals of an inch. In these rather crude experiments Young failed to note the application of the capillary flow equation, otherwise he would have discovered the important effect of cake compressibility in diminishing capillary size under pressure. In Graph "A" I have dotted in the true capillary flow curve for constant capillary area. Provided the filter cloth has constant resistance (which Young ignored), any definite sag below the ideal curve measures capillary contraction and cake compressibility. This is decidedly evident in Curve 3 of Graph C where the slime contained coarser solids than either Curves 1 or 2, but these solids were of "an amorphous clay-like material consisting principally of hydrated aluminum silicate" and therefore quite compressible.

Figures 1 and 2 show the importance of minimizing the velocity packing effect by proper sludge thickening before filtration. Fig. 3 is really shown to call attention to the fact that in all such filtration studies the initial stage of filtration produces the greatest rate of solids deposit and filtrate flow. This is due to the minimized effect of cake resistance and little more than the effect of the filter cloth resistance. The primary object of the continuous vacuum filter is to keep filtration as near this initial stage as possible by allowing but a certain minimum cake thickness resistance to form and to do this by constantly removing this cake without smearing it into the filter base and blinding it. The removal of an effective minimum cake presents the chief difficulty in attaining this object (Factor 24). In continuous vacuum filtration of sewage sludges the cake must have a certain felted body thickness and dryness before it can be peeled or stripped as an integral sheet entirely free of the filter cloth, thus leaving the cloth as clean as possible. If we could continuously, rapidly and completely strip cakes of low moisture and resistance, say of one millimeter thickness from a filter base, our chief difficulties would be over. As a matter of fact in sludge filtration a filter cake can't be much less than three times this thickness, even if quite dry. In a number of instances even this thickness discharges so poorly that partial removal soon causes smearing and cloth blinding. Definite minimum thickness and dryness of filter cake are therefore essential to proper operation of the continuous vacuum filter (Factor 24).

Factor No. 7, which relates to filter base or cloth resistance to filtrate flow, is of such importance in sewage sludge filtration that it and other factors relating to the construction of the vacuum filter itself will subsequently be discussed.

The foregoing discussion relates primarily to factors influencing filtration of all types of solid suspensions in water. However, there are additional and quite important factors relating specifically to sewage sludges. These factors are so characteristic of the extremely compressible solid aggregates of sewage solids and offer such material difficulties in vacuum filters that they will be discussed under a separate heading. Some of these properties have already been emphasized.

Although the earliest patent known to me on the continuous vacuum filter is now almost 70 years old (1872), it strangely enough was intended, among other difficult things, to be used on "sewage precipitates." This device waited for some 30 years before it independently occurred to American inventive genius and found rapid introduction and development in the metallurgical industry. The numerous filtration factors associated with voluminous and highly compressible sewage sludges stubbornly resisted the application of this device until after it had found widespread use in all other easier industrial fields. Then, after 53 years of waiting, it occurred to American investigators to change the sludge and make it fit the filter.

Factors Which Influence the Vacuum Filtration of Sewage Sludges

It has already been shown that the net effect of mineral matter in any sludge is to increase the specific gravity, stable structure of the solid particles and percentage of solids concentrated in the sludge and filter cake. The net effect of organic matter with its low specific gravity, high hydration and void volume is just the opposite.

The high compressibility of sewage sludges is practically a direct function of the organic matter present in the settleable solids. This statement follows from comparing a sewage sludge of 5 per cent solids, consisting of 28 per cent mineral matter of specific gravity 2.5 and 72 per cent organic matter of specific gravity 1, which will produce a filter cake with 25 per cent solids, with well-known examples of metallurgical waste slimes containing 55 per cent solids, consisting of 100 per cent mineral matter of specific gravity 2.5 (identical with above), no organic matter, and which will produce filter cakes of 85 per cent solids.

By making purely volumetric comparisons of the solids and voids in both of these sludges before and after filtration it can be demonstrated that the ratio of the specific gravity of the mineral portion of the sewage solids to the specific gravity of the sewage solids determines the moisture or void fraction left in the filter cake. Furthermore the void contraction per unit volume of solids (ml.) in the sewage sludge is 12 times that of the mineral sludge during filtration. Measured in this manner it is 12 times more voluminous. The finished sewage sludge cake is still 2.56 times more compressible than the mineral cake and this greater void volume or measure of compressibility is practically identical with the ratio of 72.2 per cent organic matter to the 27.8 per cent of mineral matter in the sewage solids. Of course under sufficient pressure both sludges and cakes are compressible but it should be quite evident that in sewage sludges the compressibility is largely a function of the organic matter present in the solids.

We measure the organic matter present in sludge largely in terms of volatile matter. Therefore the above statement verifies the well-known fact encountered in sedimentation and thickening of waste activated sludges, *i.e.* that settleable solids high in volatile and low in mineral matter are difficult to thicken. For identical reasons they are even more difficult to dewater by vacuum filtration.

It can be demonstrated that if the void spacing in the exemplified sewage sludge diminishes 12 times more per ml. of solids than in the purely mineral sludge while maintaining identical solid deposit rates, the effect of the diminishing void channels in the sewage sludge will necessitate increasing its filtration pressure several thousand times more than on the mineral sludge. Obviously this is economically impossible.

According to Rudolfs and Gehm (10) less than 10 per cent of the suspended solids in sewage are colloids, meaning the particle sizes are such that they readily pass through filter paper, not to mention the far grosser pores of filter cloths. The major portion of such colloids is not settled or swept down with the much coarser settleable solids. Disregarding this simple fact and granting that this percentage may be as great in settled sludges through normal fracture and attrition of coarser aggregates, it should be evident that both large and fine sewage solids are highly compressible and the effect of the colloids themselves on filtration rates is quite secondary to that of high compressibility. Only the much larger aggregates are primarily intercepted by the filter cloth and rapidly compressed under filtration pressure. Naturally this effect then traps some colloids other than those already enmeshed in the larger aggregates. This fact defeats the efforts of those seeking to prove that the beneficial effects of sludge elutriation are primarily due to the removal of some finely suspended solids in the elutriate while leaving 200 to 500 times more highly compressible solids in the elutriated sludge. Frequently there is no variation in the compressibility of solids in the same sludge before and after elutriation. Increasing filtration pressure on filter deposits of such sludge aggregates only packs them more tightly into a thin, impervious paint-like coating in and on the filter cloth, from which they cannot be removed except by scrubbing or high pressure showering.

Filter Aids and Coagulation.—As previously stated, we cannot make a square foot of continuous vacuum filter area do 2,000 times the dewatering work of a square foot of sand bed area by simply reducing the cake thickness (capillary length) to about 1/40th that of the sludge bed depth, increasing the filtration pressure 45 or 50 times and filtering during all kinds of weather. The advantages gained by these favorable changes would be entirely lost or offset by sludge compressibility unless we use some means to give the voids a larger and relatively more constant size.

In some industries, in which compressible materials are filterd, this effect is diminished by the use of "filter aids," namely some mineral or other material of granular and porous nature, which is added to the sludge to offset void shrinkage in the filter cake. These aids are of more value in batch filtration at constant flow rate, namely where filtration is gradually increased to produce a constant filtrate flow rate. This is not the case with the vacuum filter.

Young, in his cited studies (3) on vacuum filtration of purely mineral sludges, concluded that small changes in the amount of clay in the slimes or cake had more effect on filtering rates than did larger changes in the sand content. This is logical because any change in the addition of such hydrated clay particles materially adds to the sludge compressibility and small amounts of compressible solids can rapidly diminish the capillary voids through which filtrate must be forced. (See Fig. 3, Graph C.)

The idea of reversing this procedure and adding coarse filter aids originated in industrial filtration and found introduction to sewage sludge dewatering. This was done, however, without adequately understanding the large compressibility factor characteristic of sewage solids. Oddly enough, our patent literature is replete with old and recent schemes for adding clay, sand, diatomaceous earth, paper pulp and what not to sewage sludges to kill this throttling effect of compressibility. Some of these schemes were even tried commercially. The amounts of filter aids used per pound of true sludge solids were so large and the filter yields in actual sewage solids so small that no economical advantage was gained.

The simplest and most effective method of enlarging and keeping the void channels relatively open before and during filtration of sewage sludges was found to be chemical coagulation. Here we compress the solids before filtration by adding a solution of some chemical coagulating agent. Our word coagulation is derived from the Latin *cogere*, meaning to drive together. This driving together of the hydrated and voluminous sludge solids is entirely due to releasing the water solution of something from the wetted capillary solid complexes through electrochemical stress changes at the wet surfaces of such masses by adding a solution of some chemical agent. This coagulation procedure visibly releases material quantities of water from the voluminous sludge-water complexes. Simultaneously the partially dewatered solid aggregates are driven together in curdled or clumped aggregates.

Coagulation is a powerful solids compressing and dewatering step itself and renders further pressure draining of the clumped solid aggregates relatively easy. For this reason coagulation is largely responsible for enabling a square foot of vacuum filter area to accomplish so much more draining than does gravity aided by air drying on a square foot of sand bed area.

In view of the fact that specific gravity, moisture or void fraction, and therefore compressibility, of sewage sludge solids is a direct function of the volatile or organic matter present in the sludge solids, the amount of coagulants used must be likewise a direct and indirect function of volatile matter present. The full meaning of this statement will be subsequently made clear.

It is also noteworthy of attention that the natural presence of stable mineral particles in any sludge will automatically reduce the volatile fraction present and aid coagulation in several important ways, *i.e.* as a filter aid, as diminishing the amount of coagulant needed for the diminished volatile fraction, by increasing specific gravity and decreasing the moisture or void fraction present in the sludge and reducing the compressibility of the total sludge solids.

Schroepfer (11) in his exhaustive report on "Experiences in Operating a Chemical Mechanical Sewage Treatment Plant" clearly emphasizes this. The thickened raw sludge at Minneapolis-St. Paul has about the same volatile content as the digested sludge at Richmond-Sunset in San Francisco, with very low alkalinity per pound of sludge solids. At Buffalo the sand and silt in the digested sludge during the first year's operations materially reduced the volatile fraction and aided in dewatering operations. Now that this inert material is becoming less and the volatile fraction is increasing the coagulant requirements are definitely higher. As a matter of fact the mineral dirt washed into new treatment plants from newly installed sewerage results in such low chemical additions that premature publicity has frequently cheated some comparatively unnoticed natural filter aids out of a lot of credit given to designing and operating acumen.

The important additional factors relating only to the vacuum filtration of sewage sludges necessitates expanding our general list to include the various effects of organic matter (indicated by a new No. 3 and additional numbers from 26 to 32).

3. Nature of sludge solids (type of sludge, volatile and mineral content, density of both and of sludge solids and sludge).

26. Amount of biochemical and other reagents in the moisture (bicarbonates and reducing agents in p.p.m. and pounds per lb. of sludge solids).
27. Kind of coagulant used.
28. Amount of coagulant used per pound of volatile and total sludge solids.
29. Agitation mixing of coagulant and sludge before and during filtration.
30. Kind of floc produced (coarse or fine).
31. Amount of cake scouring and sloughing as drum rotates.
32. pH of filtrate and relative viscosity.

As previously indicated some of these factors are interrelated, like volatile, specific gravity, moisture, alkalinity and ferric dosage, etc. Some can be readily controlled in plant operation and the importance of others is best studied by preliminary Buechner filtration tests, provided such tests are run to a cake thickness approximately similar to that desired in the filter.

Factors 1 to 5, 7, 8 and 24 have already been discussed. The subject of vacuum production and usage will be discussed later for reasons of convenience. Without the use of coagulants this subject would be of no use to us. The effect of volatile matter on the amounts of biochemical reagents in the sludge moisture and coagulant additions will be discussed shortly.

(*Factor 26*) *The amount of natural biochemical reagents dissolved in the sludge moisture* has definite influence on No. 28 (amount of coagulant used) and other factors like 30 (kind of floc produced), 7 (filter cake, yield, resistance, etc.) and 22 (filter speed), etc.

In his discussion of Jones' paper (27) on "Progress in the Conditioning of Sewage Sludge for Dewatering" (12) Faber states, "While the average per cent of solids in these types of sludges may reasonably be related to average yields of filter cake obtained, such relation is highly questionable. It is necessary to consider the extreme variations of maximum and minimum figures which comprise the averages. When this is done, it will be apparent that many factors other than per cent solids determine the yield of filter cake." To emphasize this statement Faber shows the following table:

Type of Sludge	Per Cent Solids in Sludge			Filter Cake, Lb./sq.ft./Hr.		
	Max.	Min.	Average	Max.	Min.	Average
Raw, fresh	10.9	0.6	4.7	15.0	1.0	5.2
Raw, stale	6.0	5.0	5.5	5.0	3.0	4.0
Raw, concentrated	14.0	2.0	7.5	15.5	1.2	5.6
Digested	16.0	4.0	8.5	14.8	2.5	8.5
Digested, elutriated	12.0	2.9	7.9	7.5	5.4	6.6

In view of the large number of factors herein listed and factors evidently suspected by Faber, one can see that the data presented are meager. However, these data can be further analyzed with new light on the subject by relating moisture to pounds of solids and rearranging the tabulation:

Type of Sludge	Per Cent Water		Per Cent Solids		Lbs. Water p. Lb. Solids		Per Cent Diff. between Max. and Min. foregoing	Per Cent Diff. between Max. and Min. Cake Yields
	Min.	Max.	Max.	Min.	Min.	Max.		
Raw, fresh	89.1	99.4	10.9	0.6	8.2	165.7	95.0	93.5
Raw, conct'd	86.0	98.0	14.0	2.0	6.14	49.0	87.5	92.3
Raw, Stale	94.0	95.0	6.0	5.0	15.7	19.0	17.4	40.0
Digested	84.0	96.0	16.0	4.0	5.25	24.0	78.1	83.1
Dig. elutriated	88.0	97.1	12.0	2.9	7.34	33.5	78.1	28.0

Examination of the last two columns presents an interesting picture. In the fresh raw and thickened raw sludges the per cent difference between the maximum and minimum amounts of moisture per pound of solids is almost the same as the per cent differences between maximum and minimum cake yields. However, with the raw, stale sludge the picture is entirely different. There is but about 17 per cent difference in the moisture per pound of solids and over twice (2.3 times) the difference between maximum and minimum cake yields. Evidently something within the sludge moisture itself has materially changed. In the digested sludge this difference in the maximum and minimum moisture per pound of solids is definitely less than in the case of the fresh raw sludge, although its relationship to difference between extreme cake yields is again about the same as in the thickened raw sludge.

When we come to the elutriated digested sludge the entire picture is reversed. Although the per cent difference between maximum and minimum pounds of water per pound of solids is identical with the unelutriated sludge, there is but 28 per cent difference between extreme filter yields, *i.e.* just about one-third the difference tabulated for digested sludge. This should be good evidence that much depends on the concentration of some natural reagents in the sludge moisture when we use coagulants.

The influence of the concentration of ammoniacal bicarbonates in the sludge moisture on coagulant additions (Factor 28) has been emphasized by myself and others in previous publications (13).

In this respect it should be remembered that ferric chloride added to ammoniacal and other bicarbonate solutions produces a solution of ammonium chloride (or other chloride if other bicarbonates are present), a precipitate of ferric hydroxide, and liberates carbon dioxide. This fresh precipitate is so colloidally dispersed that it will flow through filter paper. When flocculated by standing or other means it becomes highly hydrated and forms a filter cake so voluminous (gelatinous) that it is as difficult to filter as uncoagulated sewage sludge. As before stated both the hydroxides of aluminum and ferric are classic examples of compressible precipitates. Ruth (14) shows that ferric hydroxide filter cake obtained under high pressure varies in moisture from 98 per cent at the solid depositing zone to 85 per cent in the layer next to the filter cloth. Under these conditions why do we use ferric and aluminum salts as coagulants?

We add ferric chloride solution primarily for coagulation, which has already been described. Because this coagulant solution has to primarily act through the free sludge moisture solution we actually:

(1) First produce unavoidable chemical solution reactions in the sludge moisture, *i.e.* the above reaction with ammonium and other bicarbonates takes place, precipitating highly hydrated ferric hydroxide. The hydrated ferric complex helps coagulate the hydrated sludge solids and becomes itself coagulated in the reaction.

(2) Enough surplus ferric chloride is added to act directly with the reacting bicarbonates and other reagents trapped within the spongy or capillary porous structure of the sludge solids themselves. This is the direct action primarily intended and therefore the most important for our purposes.

(3) Ferric chloride, being a powerful oxidizing agent, is partially used in oxidizing some organic and perhaps some inorganic matter dissolved in the sludge moisture. In dosing digested and raw sludges with ferric salts definite amounts of ferrous salts are found in the

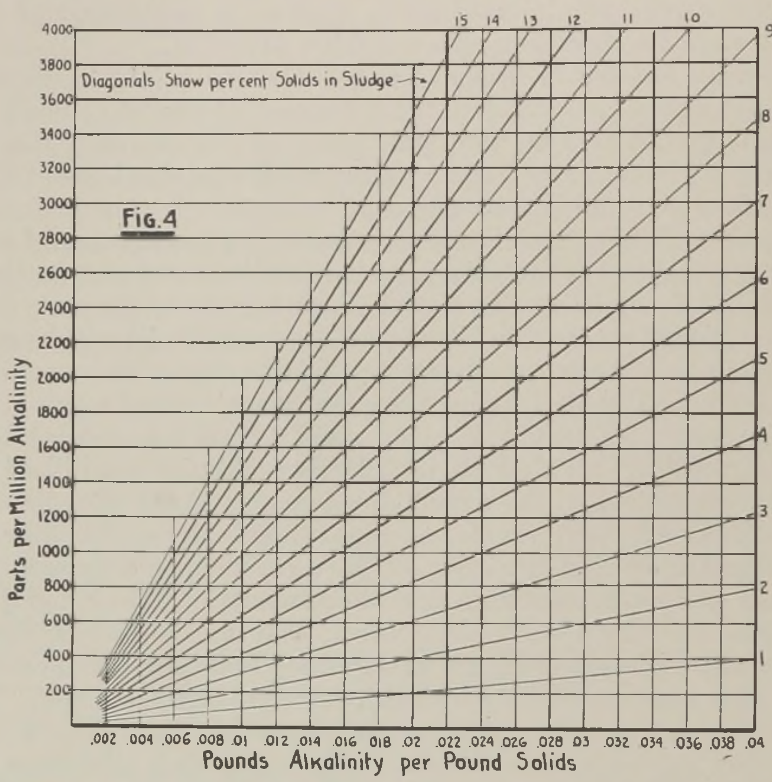
filtrate. McNamee (25) states that about 23 per cent of the ferric chloride added to the elutriated sludge at Washington, D. C. is found in the filtrate as ferrous chloride.

Obviously, with relatively high concentration of bicarbonates in the sludge moisture and with high sludge moisture per pound of solids, undue amounts of ferric hydroxide can be formed per pound of solids present. The result is high compressibility resistance to free filtration of the coagulated solids. Low cake yields of high moisture content follow. This is exactly what happens with some sludges. It doesn't take much excess precipitated ferric hydroxide per pound of sludge solids to show its throttling effects during filtration.

Alkalinity Related to Sludge Solids.—McNamee (15) in his studies of digested sludge liquor states, "it is found that almost as much ferric chloride is needed to filter the liquid itself as is required if the sludge is present." The sludge liquor investigated contained about 0.4 per cent solids and roughly 99.5 per cent water which contained, among other solubles, 3627 p.p.m. alkalinity. Measuring this in terms of solids it calculates to about 0.361 lb. alkalinity per 99.5 lb. water and 0.4 lb solids or 0.903 lb. of alkalinity per pound of sludge solids present, *i.e.* 90.3 per cent. To get reasonable filtration rates from this liquor, doses varying from 60 to 116 per cent ferric chloride on the solids present were used. Taking a digested sludge from McNamee's tables which contains about the same alkalinity, 3625 p.p.m., and 8.2 per cent solids with 91.8 per cent moisture, we find about 0.04 lb. alkalinity per lb. of solids present, or about $\frac{1}{23}$rd the amount present per pound of solids in the liquor. Roughly $\frac{1}{22}$nd the ferric doses required for the liquor was used to produce rapid filtration. The same principle applied to the elutriated sludges listed shows that similar relationships roughly exist, which is noteworthy when one remembers that in making such Buechner tests the rates of depositing the precipitated and coagulated complexes during filtration vary widely with thinner and thicker sludges. To determine this factor more reliably, such Buechner tests should be conducted with approximately the same cake yields and with other previously listed influences taken into account. Obviously variations in moisture and concentration of reagents in the moisture can go hand in hand, namely, a low alkalinity and high moisture can be approximately equivalent to a high alkalinity and low moisture, when other factors are accounted for and the alkalinity is related to each pound of solids present.

Figure 4 has been prepared to make this evident. Here the p.p.m. alkalinity in the sludge moisture are plotted against pounds of alkalinity per pound of sludge solids present, for sludges ranging from 1 to 15 per cent solids, represented by the diagonal lines. Thus a sludge having 1 per cent solids and 200 p.p.m. alkalinity in the moisture will have about 0.02 lb. alkalinity per pound of solids, which is equivalent to a sludge having 9 per cent solids with ten times as much alkalinity in the moisture, or 2000 p.p.m., or a sludge having 13 times as much solids and 15 times the alkalinity concentration, *i.e.* 3000 p.p.m.

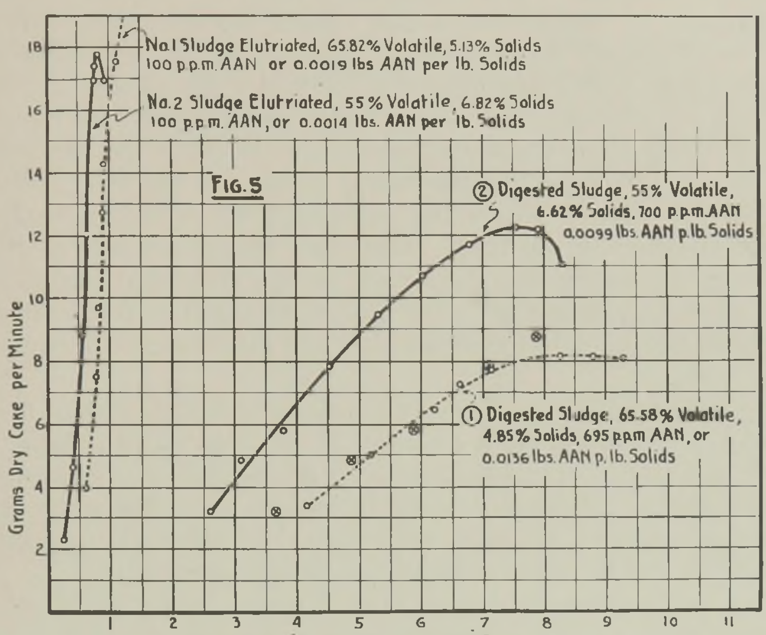
This graph is simply intended to show that the amount of ferric hydroxide formed per pound of sludge solids can be approximately the same when adding ferric chloride to sludges having the same amount of alkalinity concentration per pound of solids. Other decomposition products present in the sludge moisture may not only act as ferric reducing agents but also form other ferric consuming precipitates or compounds with the added coagulant. However, with low solids and



high alkalinity undue amounts of highly compressible ferric hydroxide per pound of sludge solids are formed for good filtration.

Sludge elutriation is now widely used for removing most of the effects of such biochemical reagents from stale raw and principally from digested sludge, which is comparatively rich in ammoniacal bicarbonates. Although this procedure does not change the volatile fraction and compressibility of the sludge solids, with proper sedimentation equipment it can make the void fraction (sludge moisture) somewhat less, and it materially changes the concentration of alkalinity in the void fraction (alkalinity per pound of volatile and total solids present) and reduces the coagulant required per pound of solids while increasing filter yields through coarser floc production.

Effect of volatile on coagulant.—We use coagulants chiefly to curdle and clump the organic structure or portion of sludge solids, therefore a well elutriated sludge having a high volatile fraction will automatically have somewhat more moisture per pound of solids and require more coagulant than does an elutriated sludge having low volatile and less moisture. Examination of Fig. 5 makes this evident. However, as will be seen presently, without elutriation the combined volatile, moisture and alkalinity effects on coagulant addition are greatly multiplied. In addition to this the oxidation-reduction action of ferric salts and organic matter is most probably related to the volatile content.



These facts seem to have been overlooked heretofore because I have seen no published data relating ferric doses to volatile matter present in any sludge.

Figure 5 is intended to show the combined effects of volatile and ammoniacal bicarbonates on ferric chloride doses and equivalent Buechner solids yields on unelutriated and elutriated digested sludges. These studies were made about five years ago at Baltimore shortly after the new Dorr-Keefer separate digestion tanks were put into operation. The ammoniacal bicarbonates present were determined in terms of p.p.m. ammoniacal nitrogen and the ferric doses plotted against dry solids cake yield per minute.

The sludge of Curve 1 has definitely more volatile than does No. 2 *i.e.* 19 per cent more and 37 per cent more ammoniacal bicarbonates per pound of solids present. These two factors combined amount to 56 per cent more for Sludge No. 1. Multiplying the dosages used for No. 2

by 1.56 produces the crossed circles shown near Curve No. 1. No match of calculated values with experimental plots should be expected where No. 1 flattens out, evidently because the cake compressibility becomes more pronounced at higher experimental ferric chloride doses, i.e. undue amounts of ferric hydroxide are formed. Because of greater volatile matter, moisture and ammoniacal bicarbonates in No. 1, the floc formed by coagulation is definitely more compressible throughout its entire range than is the case in No. 2, where more mineral matter undoubtedly helps in reducing sludge and cake compressibility.

The influence of volatile matter in producing much less ferric hydroxide per pound of sludge solids, less sludge and cake compressibility and more actual coagulation of the sludge particles with coarser floc formation is plainly seen from the graphs at the left, produced by counter-current elutriation of original sludges Nos. 1 and 2. Original sludge No. 1 contained 7.2 times as much ammoniacal bicarbonates per pound of solids (and about the same volatile) than did the elutriated sludge No. 1. Multiplying the ferric doses for the No. 1 elutriated sludge by 7.2 almost brings the calculated curve values back to the original experimental position. However, this is entirely as it should be if the much smaller coagulant doses on the elutriated sludge produce coarser sludge coagulation with less compressible ferric hydroxide precipitated per pound of sludge solids and therefore more rapid drainability.

The relative positions of the two elutriated sludge graphs are again due to No. 1 elutriated sludge having 22 per cent more volatile and 36 per cent more ammoniacal bicarbonates per pound of solids than No. 2 elutriated sludge, *i.e.* the combined ratios are about the same as in the unelutriated sludges, but with materially less alkalinity per pound of sludge solids and therefore less ferric chloride consumed.

Undoubtedly these factors of void fraction (moisture volume), reagents dissolved therein, volatile fraction and compressibility go hand in hand. However, the amounts of precipitating and reducing biochemical reagents present in the void fraction per pound of solids profoundly influence coagulant additions, final sludge compressibility and drainability. This means that elutriating a digested sludge of relatively high moisture, volatile and alkalinity content requires thorough washing with water relatively purer than normally required.

(*Factor 27*) *Kind of Coagulant Used.*—This has a definite influence on amount of coagulant used (Factor 28), method of agitation mixing (Factor 29), kind of floc produced (Factor 30), filter cake yield and moisture (Factor 7) and therefore filter speed (Factor 22), kind of filter cloth used (Factor 18), pH of filtrate (Factor 32) and therefore possibly on the filtrate viscosity (Factor 9).

Ferric chloride is superior to chlorinated copperas and ferric sulfate. The reasons for this have been previously published (16). In some plants, like Baltimore and Annapolis, the price of coagulant determines the kind used.

Ferric chloride is used preferably alone on activated and elutriated sludges. In such cases it produces a very coarse floc under proper mixing conditions (Factor 29) which is rapidly dewatered with proper filter construction and operation.

In using ferric chloride and lime the added lime hydrate combines with carbon dioxide gas and bicarbonates present in a sludge to form granular mineral lime carbonate, which actually reduces cake compressibility by acting as a filter aid. However, under conditions of high ammoniacal bicarbonate concentration in the sludge moisture, this gain in filter aid can be entirely lost because the reaction liberates ammonium hydroxide, which reacts, as already shown, with the added ferric chloride to form undue amounts of highly compressible ferric hydroxide. Ferric hydroxide formed from ammonium hydroxide solutions is practically unfilterable. For this reason lime can be detrimental in some digested sludges, *e.g.* digested activated. Partial elutriation of such sludges may render the use of small amounts of lime, with ferric chloride, of some economic value. This subject is one of further laboratory research. However, on elutriated stale raw and primary digested sludges the use of ferric chloride alone is preferable for reasons already disclosed.

Van Kleeck (7) states that sludge floc produced by ferric chloride alone is unstable. Although all flocculated aggregates produced by coagulation are relatively unstable, it is my opinion that the sludge floc referred to owes its instability chiefly to the unstable ferric hydrate formed. The natural floc of digested sludge is notably stable throughout months of digestion and storage time. Attention has already been called to the remarkably high hydration and compressibility of ferric hydroxide. This property is augmented by standing, particularly when the hydroxide has been precipitated from ammonium hydroxide solutions in the absence of all sludge solids.

(*Factor 28*) *Amount of Coagulant Used.*—This is a function of the combined influences already discussed. Within certain wide limits filter yields (Factor 7) are a function of the amount of coagulant used. This follows from the foregoing considerations. It is particularly true of sludges coagulated with ferric salts alone, *i.e.* waste activated, fresh primary raw and all elutriated sludges.

As before mentioned in collecting data on this subject we should also record the coagulant dose in percentage of volatile matter present in the sludge.

(*Factor 29*) *Agitation of Coagulant and Sludge Before and During Filtration,* (*Factor 30*) *Kind of Floc Produced,* and (*Factor 21*) *Distribution of Coagulated Sludge Freely Throughout Sludge Bath* are related and are of material importance because they account for some of the differences in coagulant dosages and filter behaviors.

It is essential to the successful operation of any continuous filter that the coagulated sludge fed to it be as uniformly coagulated as possible. Proper mixing of coagulant and sludge is essential in providing this condition. However, even with well mixed sludge and coagulant before and during filtration, faulty mixing can have very detrimental effects by homogenizing the mixture too much. In other words for filtration purposes *there is a material difference between a uniformly coagulated sludge and a thoroughly homogeneous sludge,* coagulated or otherwise.

It should be evident from a glance at the equation for capillary flow rates that after purposely augmenting the void channels of any sludge by proper coagulation, prolonged stirring at low rates and too violent agitation for brief periods may increase homogeneity but can and does necessarily reduce sludge aggregate size, thereby increasing filtration resistance. According to this equation it doesn't take much reduction in particle or floc size to effect this change.

It is also noteworthy that this fact is not limited to sewage sludges. It is relatively just as vital in the filtration of quite rigid mineral particles. The particle grinding or attrition effects of keeping constant sludge levels in continuous vacuum filters by overflowing surplus mineral slime feed and recirculating it in pumps before, and after filtration, together with filter mixing have long been known in the metallurgical industry. Ruth (17) in his studies with pressure filtration of relatively rigid mineral particles without coagulation states, "A definite law appears to govern the increase in filtration resistance with time of stirring." With the more fragile floccules produced in water clarification and sludge conditioning this effect is most pronounced. Keefer and Kratz (18) have demonstrated the detrimental effects of too much stirring on sludges before and after coagulation.

Fortunately coagulation with ferric (or aluminum) salt solutions alone is so exceedingly rapid in dosing waste activated and elutriated sludges that flash mixing of sludge and coagulant can be and should be employed. The world's largest vacuum filter installation at Chicago, handling waste activated sludge, and some installations filtering elutriated sludge, particularly that at Annapolis, Md. (19), have amply demonstrated this fact. As will be shortly shown, however, a great deal depends on filter construction, installation, submergence and operation in obtaining the best results from such practice.

In using ferric salts alone on unelutriated stale raw and digested sludges copious quantities of carbon dioxide gas are liberated. Unless this gas is first thoroughly stirred out of the void fraction of the sludge, sloppy, porous and pitted cakes result. Aside from giving the vacuum pump more work to do in filtering out this gas, the cake is quite compressible and wet. This fact automatically calls for prolonged, but not vigorous mixing before filtration, whether in plant practice or in making laboratory Buechner filter tests. Elutriation removes this necessity.

In dosing any sludge with lime and ferric salts rapid flash mixing cannot be used for several reasons, *i.e.* two chemicals are used and precipitation of lime carbonate, liberation of hydroxide, formation of ferric hydroxide and sludge coagulation all require time and better mixing. Much larger mixing equipment is needed here than for flash coagulation.

In the absence of proper facilities for flash flow mixing mechanical stirring of sludge and coagulant, even for a very brief period, is definately superior to the use of compressed air. The latter method is not only inefficient from a power and mixing standpoint, especially with thick sludges, but can cause too much floc attrition, requires thoroughly enclosing the mixing chamber, and pumps air into the sludge for the vacuum pump to exhaust.

From the foregoing considerations it should also be evident that conducting coarsely coagulated sludges from a central point to various filters through long inverted pipe mains can also cause unwanted floc fracture through flow attrition. It should be remembered that after coagulation the sludge is materially more viscous and resistant to flow through piping. Therefore in using flash mechanical mixers for ferric chloride alone, where there is little or no gas evolution during mixing, it is better to use a small mixing chamber equipped with variable speed stirrer at each filter or equi-distant between two filters, with short, level (not inverted) feed piping between the mixer and filter. This arrangement is used at Springfield, Mass., with excellent results.

A sludge can be too heavy and viscous to permit proper rapid mixing with coagulants. In such cases both coagulant and sludge must be diluted with water. The writer has seen several installations where, through having the sludge too heavy or through lack of proper baffling in the mixing chamber, the conditioned sludges frequently lack uniform mixing and coagulation. This is always evident in the cake deposited on the filter drum. Streaked cake with over- and under-conditioned zones are quite visible. This condition soon leads to cake smearing and cloth blinding.

Agitation During Filtration.—Oscillating agitators in the filter tank were developed in the chemical and metallurgical industries where it is entirely necessary to prevent classification of coarser granular materials from finer solids during filtration, *i.e.* to secure uniform sludge conditions. However, after sewage sludges have settled to their maximum solids concentration there is little chance of such classification in the time taken to dewater such sludges, even after proper coagulation.

It is therefore the writer's opinion that such agitators are useless for certain coarsely coagulated sludges and in some instances detrimental to good results. If they are to have any advantage the present construction should be changed. They undoubtedly prevent sedimentation classification in a filter, but in doing this they aid in breaking down coarsely coagulated complexes, and scour some cake from the drum, which latter two facts are detrimental to good results. In addition to this, present agitators completely fail to distribute inflowing freshly coagulated sludge lengthwise throughout the filter tank (Factor 21). Their construction and oscillating swing simply move the incoming sludge back and forth in a limited zone or streak, thus producing lengthwise classification of new and old floc while preventing vertical classification of coarser solids. As will be shown they cannot always do this. Any lengthwise classification can be decidedly detrimental in cases where the coagulant dose is changed either to increase cake yields or to decrease them. An increased dosage will become evident only in the drum zone opposite the sludge inlet to the filter. The older sludge remains in the two end zones, and may start cloth blinding at the filter ends. Coversely with dosage decrease the wetter sludge will become zoned opposite the sludge inlet. In the Oliver Filter the sludge

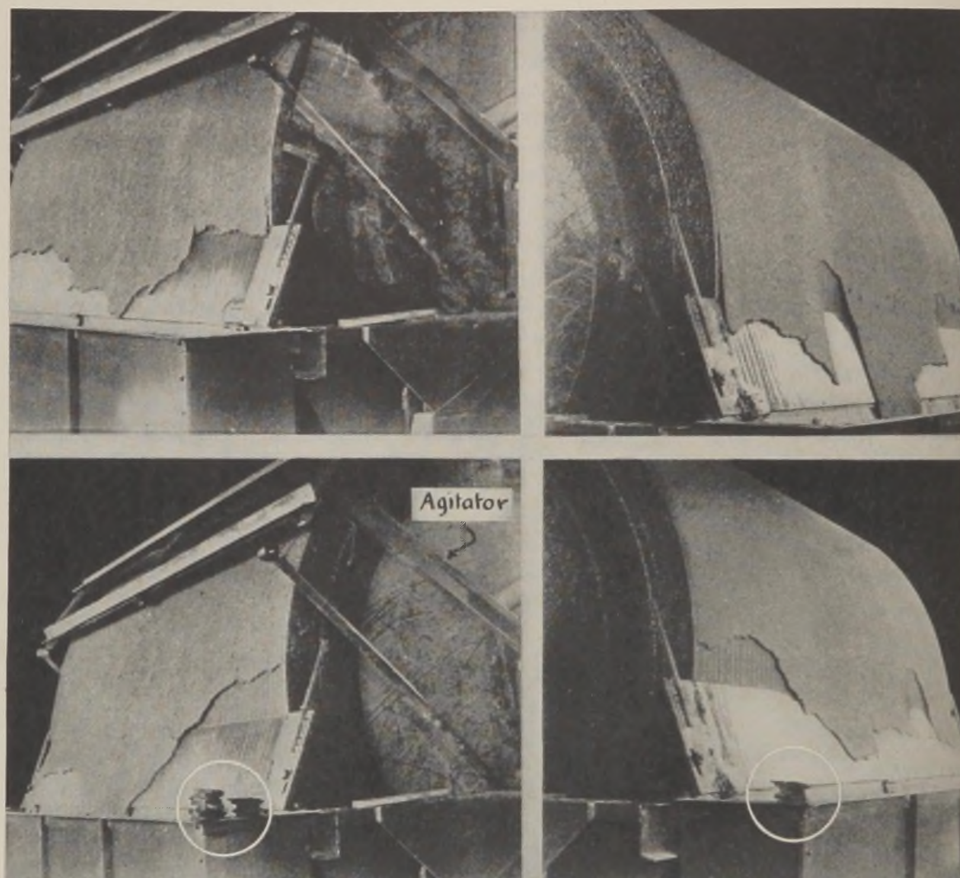


Fig. 6.

depth in the filter tank can be lowered without decreasing the vacuum, which fact enables one to have the agitator swing definitely out of submergence. In any case with well coagulated sludges the present agitators definitely scour some cake (Factor 31) from the drum surface.

To prove the inefficiency of lengthwise sludge mixing and distribution (Factor 21) and the efficiency of cake scouring (Factor 31) and floc destruction Fig. 6 is shown. The photographs were taken from a position equidistant between two continuous vacuum filters dewatering coarsely coagulated sludge. In one filter the agitator was disconnected from its driving mechanism and rotated completely out of the filter tank and fastened over the filter drum, leaving the tank entirely free of any baffling action to sludge distribution in the tank. It was found that merely stopping the agitator helped some, but removing it from the tank helped considerably more. In the other filter, fed from the same mixing tank, the agitator was left to operate as intended. In the tank without any agitator (left side of Fig. 6) variations in dosages quickly distributed themselves throughout the filter tank, the floc remained coarse and the filter cake was 50 per cent thicker than on the right hand filter, with the agitator running. Within the white circles are shown eight layers of cakes from each filter on the sludge hopper of the left hand filter and eight layers of the thinner cake on the hopper of the right hand filter from which these thinner cakes came. The photographs show definite zoning of overdosed sludge in the center of the drum with agitator running and no such zoning in the other filter. Furthermore the cake discharge blow-back on the filter with agitator operating was wetter due to wet and dry cake zones on the drum.

Any agitator construction which insures gentle but complete sludge distribution lengthwise over the filter drum surface will be a material improvement. The effects of cake scouring and floc destruction may then become of minor importance. Undoubtedly this subject and its associated factors needs more observation and study. This matter will be subsequently mentioned with relation to another serious defect in vacuum filter construction.

7. *Cake Thickness, etc.*—The subject of minimum practical thickness has already been discussed. This doesn't bother us in making Buechner filter tests, where we always use a new and clean medium for each test and don't do a lot of other things a filter operator has to do on account of filter construction and layout.

Frequently filter yields and coagulant additions are reported when the filter drum is not completely discharging all cake and material portions of total filter area are blinded. Recording results without reference to this fact can lead to erroneous conclusions in analysing monthly or yearly factor averages.

Wherever cake yields are weighed and recorded as pounds of dry solids per square foot filter area per hour a correction for the weight of chemical precipitates formed and included in the filter cake should be made, in order to give a more exact recording of the coagulants used per pound of true sludge solids. The use of lime adds material quantities of inert material to any sludge cake weight. Each weight unit of ammonium bicarbonate present in sludge moisture requires 0.71 units of lime (CaO) to form 1.264 units of calcium carbonate. Usually free carbon dioxide gas and calcium bicarbonate are also present and increase lime requirements and carbonate formation. Instances exist where, with low sludge solids and high moisture alkalinity, the vacuum filter is a lime carbonate dewatering device rather than a sewage sludge filter.

In order to obtain relatively exact data on coagulant addition related to all sludge characteristics and all the listed basic factors, properly conducted Buechner filter tests should be made.

(*Factor 31*) *Cake Scouring or Sloughing Due to Coarseness of Sludge Floc and Vacuum Filter Construction and Operation.*—One of the principal discrepancies between Buechner filter tests and vacuum filter results is considered under Factor 31. The coarseness of the sludge floc formed by ferric chloride alone is at times so great as to produce excellent laboratory results and very poor plant results. The writer has noticed this in several plants. It is entirely the fault of the manner in which rotating drum filters are constructed and have to operate. As paradoxical as it may seem, a thick and well flocculated sludge is frequently, if not always, detrimental to good operation of some vacuum filters.

Coarsely coagulated sludges can be poured onto a horizontal filter base, like a Buechner, and the moisture rapidly drains away under suction; thereby producing an excellent cake. Gravity not only acts in the same direction as filtrate flow, but the soupier top portion of the contracting wet cake is exposed directly to the atmospheric pressure and likewise moves downward toward the filter base during draining. With cake production on the rotating drum filter base of a vacuum filter everything is in the reverse direction, namely, the coagulated solids are deposited upward on a rotating base inverted in the sludge bath and the atmospheric pressure has no direct access to the soupy cake surface until it emerges from the sludge bath.

Any cake forming in the sludge bath is most compact at the filter cloth and becomes progressively wetter and mushier with increasing thickness until it is of the same consistency as the sludge bath itself. If the floc is coarse and easy to drain and the drum is submerged in too much sludge a very thick deposit of this mush will rapidly accumulate on the rotating drum. Then as the rotating deposit emerges from the bath the increased effect of gravity plus the material viscous drag of the thickly coagulated sludge bath will remove that portion of the thickened deposit insufficiently compacted to resist the scouring, shearing and increased gravity action. This combined action frequently drags portions of legitimate, rotating thickened but mushy cake from the drum at the rear or emerging side of the filter, where it accumulates in the tank in thickened masses only to aggravate all of the conditions described. With deep drum submergence, at every movement of the sludge agitator in the direction opposite to the rotational direction of the drum, the bath of sludge drops with the agitator swing and intensifies these conditions. The net result is a very uneven cake with frequent bare areas or very thin cake areas on the filter cloth. The thinner areas under the free action of suction become covered with fractured floc produced by the agitation and scouring action and which should normally become enmeshed in the coarser floc. Thus there is a floc classification action at the rear of the filter. Upon drying, the thinner portions, being less than the allowable minimum (Factor 24) fail to discharge and rapidly blind the filter cloth. (See Fig. 7.) This disease soon spreads throughout the filter.

This troublesome factor cannot be completely cured but it can be alleviated, *i.e.* (1) By decreasing the viscous drag area of the sludge bath through dropping the sludge level in the filter well below the extreme swing of the filter agitator. This permits better mixing of the thickened material accumulated at the emergence level and forms less cake. This can't be done with some filters without causing the cake forming vacuum to drop, thus making matters worse. (2) In the light of what has already been said of the inefficiency of the standard agitator to distribute sludge, together with its cake scouring action it may help to use low submergence and remove the agitator from the filter tank.

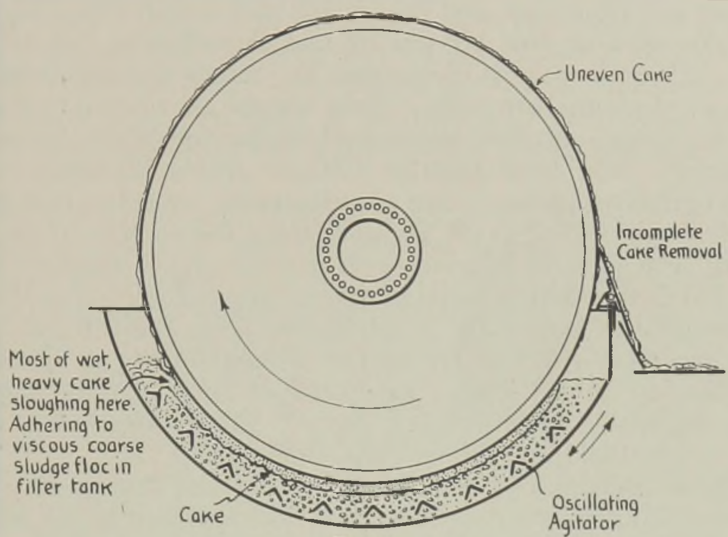


FIG. 7
When Floc is too Good for Filter

(3) Where the ferric mixer has a variable speed mechanism it is set at high speed to homogenize or beat up the coarse floc in order to produce a sludge bath having less viscous drag and a more compact but somewhat thinner cake. This last alternative seems to be the most reliable in all cases where the submergence level cannot be sufficiently lowered. In any case it is rather illogical to produce an excellent floc and then deliberately make it finer merely on account of the construction of a filter purposely intended to dewater well flocculated sludges. This factor certainly deserves more attention on the part of filter designers and manufacturers. At Annapolis, Md., and Springfield, Mass., this coarse floc is purposely produced and although there is some scouring action the results are excellent. In both cases good floc distribution in the filters is provided. At Springfield operating the filters at 6 to 8 min. p. rev. helps reduce scouring.

(*Factors 8 and 22*) *Time or Filter Drum Speed.*—Among the numerous factors having relationship to the drum speed are about five general filtration factors, six basic factors for sewage sludges and five vacuum filter construction factors, *i.e.* 1, 2, 4, 6, 7 (total effective area used, amount of vacuum, sludge moisture, filter cloth resistance, cake resistance), 27, 28, 29, 30, 21, 25 (kind of coagulant used, amount used, mixing before and during filtration, kind of floc produced, sludge distribution in filter, uniformity conditions) 13 to 17 inclusive (drum diameter, number of drum compartments, fraction of former in total effective use for cake forming and drying, fraction submerged and fraction collecting cake).

A filter drum is constructed with independently sealed compartments entirely to provide continuous, automatic means of easy cake removal, free of any suction action, and to prevent such action from flooding the vacuum system with free air during and immediately following cake removal. After the cake is discharged the empty compartments travel a definite arc distance before they again become submerged in the sludge and suction is again applied without admitting free air to the compartment interior. The total angular distance travelled during cake removal and effective submergence constitutes the area fraction not used for cake building and drying. Proportioning the number of drum compartments economically possible with a given drum diameter so that the total effective fraction forming and drying cake remains at a maximum is equally as important in small and large diameter filters. In any case the total effective fraction of compartments in effective use depends largely on the sludge submergence level and the line under submergence where cake forming starts. All compartments between the cake removal and this line are necessarily dead.

The three functions of depositing, drying and discharging a filter cake in a continuous vacuum filter are tied together in the drum periphery. No matter how much we change the drum speed we cannot separate the one from the other. As it is absolutely essential to have the cake sufficiently thick and dry for automatic removal from the drum and with proper coagulation and operation it is relatively easy to produce the desired thickness, the drying and therefore the cake compacting portion of the revolving drum demands the most time and area factors. This logically follows from what has been said about the effect of diminishing void (moisture content) on filtrate flow.

In filters automatically applying suction to drum compartments just completely submerged, the relationship between the fraction of drum surface used to form cake and the fraction used for compacting and drying is largely a function of the sludge level in the filter tank. Such filters can operate only at a fairly constant sludge level. The Oliver Filter has a movable bridge in the automatic filter valve which permits further control of the cake forming area, *i.e.* (Factor 17) of the level below actual drum submergence at which cake formation begins under suction. This is an excellent feature where a coarse floc formation permits one to operate at a very low submergence without losing the vacuum. Coarse floc with low submergence at high vacuum results in a long cake compacting or drying period and should permit increasing drum speed or decreasing coagulant dose. In all cases the time it takes to form and dry cake depends on the drum speed and the sludge level. Increasing the sludge level increases cake formation area and decreases the drying area.

Filter manufacturers have doubtless given considerable attention to the foregoing facts. However, in my opinion, further improvement is needed because the number of compartments for identical filter diameters differ somewhat with different manufacturers, are not listed in their printed matter and the cake removal deflectors are invariably supplied for high level submergence without due regard to dead area fraction increase if coarse floc and low submergence is to be used. If low submergence and suction application is best for coarsely coagulated sludges, then obviously the cake removal means should be set with some variation in level adjustment at a level lower than that normally supplied in some filters, in order to provide a longer drying arc, which helps cut coagulant addition, while further minimizing the dead area arc.

As filtration rates are largely a function of the amount of coagulant added, which in turn is a function of other factors already listed, a relatively high filter speed of 1.5 to 3 minutes per revolution requires thorough coagulation with thin sludges and good coagulation with heavy sludges. Natural mineral solids in the sludge can contribute material help in obtaining this condition. If the coagulant dosage is diminished, the filter speed should be reduced and frequently the sludge level should be dropped to provide a longer arc of cake drying. The minimum thickness of dry cake (Factor 24) that can be thoroughly discharged under all of these conditions is probably one of the most important factors. With this factor in view, the filter speed, submergence and dosage largely control filter yields. Regulating the vacuum for this purpose is poor practice as will be shown.

Schroepfer (11) excellently exemplifies the relationship between chemical dosage and filter yields at Minneapolis-St. Paul. For conditions existing in that plant it was found more economical to cut down individual filter yields by decreasing chemical dosage and using more filter units at a lower speed in order to handle the daily tonnage, than it was to use more chemical, increase the filter speed and use less total filter area.

For this reason where there are but one or two filters present which operate but 7 or 8 hours daily, it may prove more economical to operate 16 hours daily at half the filter speed and a lower chemical dose. Of course this depends on the cost of chemicals and labor.

(*Factors 6 and 18*) *Filter Cloth Resistance, Kind Used and Condition.*—As already mentioned the filter base is sand in sand bed draining. As this material can only be used in horizontal supporting beds we use relatively porous and durable fabrics on vacuum filters.

It has likewise been emphasized that the filter base or cloth and filter cake both offer resistance to filtrate flow. Ruth (20) regards the resistance of the filter cloth equivalent in resistance to some definite layer of filter cake regardless of the material being filtered. He "found that the normal operating resistance of a filter cloth approaches 100 times its resistance when new. Moreover, a considerable portion of this resistance does not reside permanently in the cloth but is generated anew each time during the initial stage of filtration." In addition to this fact particles from previous filtrations become imbedded in the cloth pores and rapidly make matters worse. Frequent showering and even scrubbing are necessary to remedy this condition. Where lime is used the cloth mesh fibres rapidly become incrusted with lime carbonate, which scrubbing fails to remove. With this additional action the cloth can soon acquire a resistance to filtration greater than that of the filter cake itself.

As Ruth states, "If we could use a septum of zero resistance, the entire pressure drop would be absorbed by the cake." Insufficient thought has been given to this subject in sludge dewatering. The chief object has been to provide at low first cost a porous and fairly durable, flexible medium of small weight which can be easily applied to a filter drum and easily scrubbed or acid washed in place. Cotton and woolen fabrics have been chosen for this purpose. The resistance of all such filter bases depends primarily on capillary flow, which is rapidly diminished by normal operating conditions.

Due to the fact that the sludge floc is relatively coarse in sewage sludge dewatering, the size and spacing of the pores in a filter cloth have a material effect on filtering rates by determining the porosity of the first layer of sludge cake deposited. If the average diameter of the coagulated sludge aggregates is greater than the mean pore spacing in the cloth, filtration rates can be materially increased. Reduction in pore size which accompanies close pore spacing can mean complete neglect of the average floc size to be intercepted by the filter cloth, with the result that the pore openings can become thoroughly blocked by fine and coarse solids in the first cake layer. This action produces maximum reduction in pore area and maximum resistance of the cloth itself. Allowing some of the finer particles to pass initially through the cloth pores will permit the average coarser aggregates to be arrested and overlap the pores without decreasing cloth resistance by the first cake deposited. This resistance is then shifted mainly to the cake where it should be. String discharge filters have taken some advantage of this fact by using a light, coarse cotton gauze medium which can be readily replaced.

Hoxson, Work and Odell (21) some fifteen years ago published interesting experimental data on the relationship between the average particle size and maximum pore openings in filter cloth for various mineral products being filtered. They found that the solid particles intercepted by filter base pores formed distinct arched bridges over the latter. This reference seems to have been overlooked by Ruth and his coworkers.

Believing that pore spacing and size is a more important factor than pore size alone in dewatering sewage sludge coagulated only with ferric chloride, the writer found nine years ago at Baltimore that this bridging was very pronounced. In fact excellent cake yields resulted when using 70 mesh double crimped stainless steel wire cloth (22). Subsequent independent laboratory studies of this subject by McNamee at Washington, D. C., led him to the conclusion that similar screen cloth is better for coarsely coagulated elutriated sludge than is the cloth now in use at that plant.

Such a medium has much less resistance to filtrate flow than fabrics of cotton and wool because its resistance is that of capillary orifices and not of capillary tubes (23). Furthermore it can be kept free of intercepted particle fragments and hydrated ferric oxide deposit common to wool cloth when using ferric salts only for coagulation. It was found in the Baltimore tests with stainless steel mesh of doubled crimped plain weave that this accumulation could be prevented with proper fine jet hosing at about 80 to 100 lb. water pressure applied after daily filter runs. Any other mesh structures, *i.e.* twill, Dutch and the like, were useless. The writer is therefore of the opinion that such cloth if properly applied to drum filters will last long enough to more than pay for the increased first cost and prove the nearest approach to a permanent filter medium of minimum resistance, particularly on elutriated and possibly activated sludges which are coarsely coagulated by using ferric chloride alone.

Cloth with much loose nap, like canton flannel or wool provides relatively open pores and close spacing although such cloths are relatively short-lived and do increase resistance to flow because of spongy ferric hydrate deposits accumulating in their fabric backing. Wool is considerably more durable than canton flannel, however it cannot be used for limed sludges and the latter can. The loose nap is advantageous in keeping the cloth pores open and lessening cake sloughing. Due to the relatively high cost of napped woolen cloth it is to be regretted that heavy, long coarsely napped canton flannel is not available.

Cotton duck of rather close plain weave with a smooth surface is used in most cases where lime and ferric are employed as coagulants. This type of cloth is quite unsuited to the dewatering of coarsely coagulated sludge because of initial high cloth resistance which prevents any loose coarse flocs from becoming the initial compacted layer of the cake. As a result cake scouring and sloughing are aggravated. Therefore where the economic effects of ferric flocculation alone are to be compared with those of lime and ferric on any vacuum filter such cotton duck should never be used on the more coarsely coagulated sludge, otherwise very misleading conclusions can be drawn.

The fibres of any new cotton cloth swell materially when thoroughly wet, which can materially increase its resistance even before sludge is applied. This important fact, plus the fact that lime carbonate rapidly deposits in such wet swollen threads to further increase cloth resistance, offers ample reasons against using closely woven cotton fabrics for any sludge.

Due to the hard finish, close weave and type of weave and high cost of glass fabrics, I cannot see where they will have any value for sludge dewatering. The first samples experimentally tried were of weave and pore spacing totally unsuited to coagulated sludge. If such fabrics are given close pore spacing and open plain weave like that of metallic screen cloth, so they can easily be kept clean and open by occasional jet showering, they may prove quite successful.

Perforated rubber dressings at this date have not the proper relationship between pore size and spacing. Sewage sludges, when properly coagulated produce much more filtrate per pound of solids than do most other sludges and therefore require a far greater number of pores, properly spaced, than those now supplied in such rubber sheeting. Present bases of this type may prevent pore plugging but filter cake yields are bound to be materially diminished in using them.

(*Factors 19 and 20*) *Method of Supporting Filter Cloth and the Effectiveness of Drainage in the Leads Under This Support,* can all have flow resistance if not properly designed and installed, namely, keeping in mind (1) that filtrate flow in such leads and connecting piping is turbulent at very low velocities and therefore entirely different from that through the cake, and (2) both the cloth supporting or backing screen and these leads can become rapidly and heavily incrusted with lime carbonate deposit (where lime is used) and therefore build up a material resistance to filtrate flow. Schroepfer and Velzy have sufficiently emphasized this fact. Furthermore silica, hydrated ferric oxide and allied deposits can accumulate in the filter backing leads and materially add resistance to flow and produce higher cake moistures. All such cloth backing should be made readily removable so as to provide easy access to the backing leads. At Baltimore, Keefer (24) materially improved filtration yields and cake moistures by having the leads back of the screen supporting the filter cloth flushed with a water jet under several hundred pounds pressure, without removing the screens.

(*Factors 23 and 24*) *Minimum Cake Thickness and Method of Removal.*—There is little difficulty in removing coarsely coagulated filter cakes from a revolving filter drum, provided the scouring and sloughing action is kept at a minimum. Moist or soupy cakes are always more difficult to remove completely than those that are firmly dry. Cloth smearing and blinding come principally from insufficiently drained cakes.

In all vacuum filters, except those having a string or cord discharge, compressed air from a blower is used for cake removal. If the drum compartments of the filter are properly sealed, very little air pressure is required for this purpose. High air pressures require more power but aid in keeping the filter cloth pores open and clean. However, such pressure can so distend and strain the cloth during each blow period that the cloth soon splits under the wires. This extreme cloth stressing action and splitting become more evident if acid cleaning (muriatic) is used in removing lime carbonate deposits from the cloth fabric. With air connections and filter leads of ample size a large volume of air at low pressure is of more value for cake removal and cloth protection than is high pressure air through relatively small air connections.

Removing Cloth Incrustation to Renew Porosity.—Dilute formic and acetic acids have been used effectively for this purpose in some metal extraction industries where lime carbonate incrustation is bothersome. Weak muriatic acid has been advised and used in some sewage treatment plants. However, this acid does weaken all cotton fabrics.

Soaking the cloth-covered drum in a weak oxalic acid solution for several hours is probably best for loosening and removing ferric hydrate accumulations in the fabric backing of wool cloth. McNamee (25) found that boiling an old cloth in hydrochloric acid released 52 per cent of this deposit as an iron salt and left 48 per cent as fine sand which could be washed out. It is not possible to use this procedure in plant practice. However, a 1 per cent oxalic acid solution revived a 500 sq. ft. filter dressing sufficiently to increase its useful life 40 per cent.

(*Factors 32 and 9*) *pH of Filtrate and Viscosity Changes.*—pH of the filtrate influences the kind of filter cloth used, *i.e.* wool is best for lower pH ranges and cotton for those above pH 7. However, I do not know of any studies made on the specific viscosity of filtrates over such ranges. Coagulation materially increases the viscosity of the sludge itself by packing the finely suspended solids into aggregates of larger volume. Using ferric chloride for this purpose should automatically diminish the viscosity of the sludge moisture or filtrate by converting the bicarbonate solutions of higher viscosity to solutions of chlorides of lower viscosity.

(*Factor 10*) *Temperature.*—Temperature increase has a material effect on the viscosity of sludge moisture. It is well known that sludges heated to temperatures near or above their boiling points filter very readily. However, this effect is principally due to the action of heat in breaking down some of the natural reagents in the sludge moisture and in coagulating some suspended solids. A continuous vacuum filter cannot dewater sludge heated to its boiling point in the filter simply because all moisture would flash to steam and destroy the vacuum. Sludge temperatures below the boiling point together with cold water condensation of the sludge vapors in the vacuum piping system would be necessary.

(*Factor 2*) *Vacuum and Vacuum Production.*—This most important factor deserves first place in any discussion of vacuum filtration. However, the production of vacuum depends on special mechanical equipment and as its suction action would be useless without proper sludge coagulation, I have chosen to discuss it here. There is much to be said on this subject because one finds no reference to its economical aspect in the literature pertaining to general filtration principles.

Because sanitary engineers have been handed the dry vacuum system, evolved in other industries for operating continuous vacuum filters, and involving a dry vacuum pump with filtrate collecting receivers, moisture traps, barometric columns and filtrate pumps, they have assumed a definite economic development has been reached. However, I have seen some faulty installation drawings, specifications and operation.

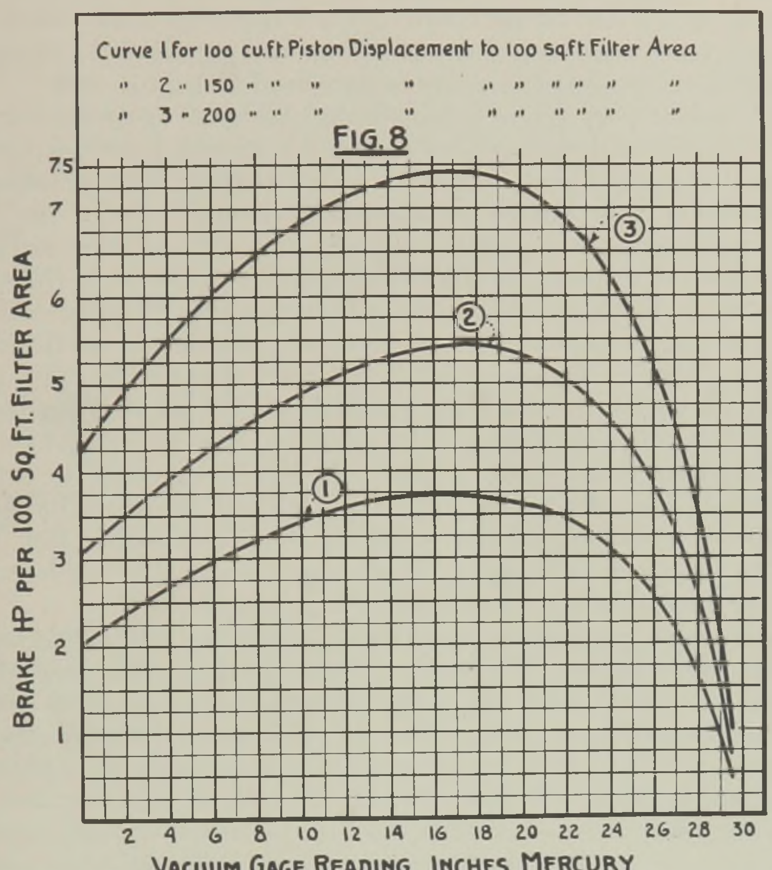
It has already been shown that filtration rates are a direct function of pressure. To obtain this pressure requires power. However, with vacuum filtration, the more atmospheric pressure we produce the less power is required beyond a certain low pressure (vacuum) range. This may sound paradoxical, but it is quite simple to understand.

Vacuum pumps are usually installed with 1.5 to 2.0 or more cu. ft. free air piston displacement for each square foot of vacuum filter area used. This proportioned ratio should be chosen so the minimum can be conveniently used, meaning that the number and capacity of vacuum pumps installed is as important as the number and size of the vacuum filters. For example, from the standpoint of power economy one vacuum pump of 900 cu. ft. piston displacement per minute for three vacuum filters of 200 sq. ft. area each may be good practice if all three filters are usually operated at the minimum displacement ratio. However, this may be erroneous practice if but one or two filters are to be normally used with this single pump.

The more efficiently we exhaust the air from the filtrate side of the filter cloth, the greater becomes the difference between the atmospheric pressure on the outside and the lowered pressure on the filtrate side. By graphing the power required throughout the range of possible vacuum production when displacing 100, 150 and 200 cu. ft. of air per minute from a given vacuum it is found that the power requirements pass through a maximum and then become lower, as shown in Fig. 8. This fact should not be difficult to understand, for if a vacuum pump were operating under a perfect vacuum, its displacement piston would be coasting along in empty space consuming only the power necessary to overcome friction. Fig. 8 is novel in that it relates the vacuum producing power consumption for 100 sq. ft. filter area to vacuum gage readings for three different ratios of piston displacement to filter area. Actual performance data sheets supplied by The Worthington Pump and Machinery Corp. for various size vacuum pumps were used by the writer for this purpose.

The graphs show that when the vacuum filters and pump are operating at approximately sea level conditions at 16 to 18 inches vacuum, peak load conditions exist for all three graphs. If the amount of vacuum can be increased, material savings in operating power result. Furthemore, if the pump displacement and filter area installed and normally used are proportioned as in Curve 2, instead of Curve 3, material power savings again result. Curve 1 is for ideal conditions and may occur but rarely.

Notwithstanding this fact I have seen filters so constructed and installations so arranged and operated that one is compelled to run the vacuum pump at peak load. In good vacuum filter operation the construction and installation of the filter and all accessory equipment should be secure against any air leaks and should permit obtaining a high vacuum at low submergence levels when the amount of coagulant added and filter speed are regulated to produce a low cake moisture and clean cake discharge. Obviously the vacuum should be kept as near the barometric available amount as possible.



Proper low coagulant dosage, slow filter speed and sludge level will result in this condition. Even with proper construction and installation conditions, if too much coagulant is used the filter cake can become very porous, due to its rapid volume (void) contraction, and develop cake cleavage and cracking long before the cake is discharged, even at increased filter speed. In this case, either the dosage should be decreased or the filter speed sufficiently increased, or preferably both, in order to keep the vacuum out of the peak load range. This is very easy to do with elutriated sludges.

An inadequately dosed sludge will automatically produce a highly compressible and impervious filter cake which so seals the drum surface that a high amount of vacuum results. In this case the high vacuum will act to pack the compressible sludge solids into the filter cloth fabric and cause rapid and complete cloth blinding. In this case the high amount of vacuum is a result and not the initial cause. Proper dosage, filter speed and level control will prevent such trouble and permit operating at a vacuum reasonably above peak load.

In visting the world's largest installation of vacuum filters at the Southwest Treatment Works in Chicago, I noticed that the filters were operating at a high vacuum well beyond the peak load range. Evidently the filter yields and cake moistures are regulated by dosage and filter speed even though the cake is delivered to heat driers.

Van Kleeck (26) reports from observation of operations in some plants, "Occasionally with heavy sludge the vacuum is reduced in order to secure a thinner and wetter cake for burning in an incinerator. Sludge incinerators can be overheated by feeding sludge that is too dry or that contains too high a volatile content." If this is done by "breaking" the vacuum, *i.e.* admitting air at some point in the vacuum system it is erroneous practice unless the vacuum is dropped sufficiently on the left hand range of the graphs shown, which may result in cloth smearing. If it is done by throttling filtrate flow at the filter, filtrate will back up within the filter and suddenly flood back through the cloth onto the belt conveyor during cake removal. In the light of the foregoing, if a cake is too thick or dry, it is more economical to cut down the chemical dose, change the submergence level, speed up the filter or do all three, while keeping the vacuum as high as possible, thus saving money in chemical and power. Schroepfer makes this evident in his report on operations at Minneapolis-St. Paul.

Considerable quantities of gases are present in unelutriated digested and stale raw sludges. The vacuum pump must exhaust most of these gases and its main work should be limited to this function and that incidental to removing the air from the filter compartments after cake discharge. Filters which cannot operate at comparatively wide ranges of drum submergence (Factors 16 and 17) without exposing filter area to suction before it is submerged, necessarily admit copious quantities of free air to the vacuum system thus compelling filtration at peak load conditions whenever the sludge level is dropped. Such thoughtless construction can therefore be quite detrimental to good filtration results.

(Factor 25) Uniformity Conditions or Constancy of Operating Averages.—The very nature of the construction and operation of the continuous vacuum filter depends on such conditions, *i.e.* uniform practical minimum void volume (moisture) in the sludge, uniform minimum concentration of biochemical reagents in the moisture fraction and volatile in the sludge solids, uniform delivery of sludge to the coagulating system and filter, uniform coagulant addition, floc production, sludge distribution in the filter, cake moisture and discharge and operation of the entire vacuum system. It is more difficult to obtain these conditions with sewage sludges than with the majority of industrial products.

In plants handling relatively uniform waste activated sludge, uniform feeding and dosing conditions are comparatively simple. In plants handling raw sludges containing storm drainage, some of these uniformity conditions change materially with dry and rainy seasons. Schroepfer's thorough analysis of Minneapolis-St. Paul results (11) shows this.

Jones states (27) "Digestion decreases the weight of solids to be handled by some 30 to 40 per cent; it provides more uniform sludge as to composition; it is less likely to produce odor; and it is amenable to washing or elutriation and a possible saving in overall cost." However, material variations in volatile, void fraction and, above all, in natural biochemical reagents present in the void fraction (moisture) of digested sludges can take place in sludge drawn from any digestion tank. These wide variations can have more immediate effect on coagulant additions and uniform filter operations than is common to dewatering practice on fresh raw and waste activated sludges. Therefore a digested sludge storage tank or well with proper mixing equipment to produce a uniform feed to the filter system is, as Jones emphasizes, advisable.

However, elutriation of any stale raw or digested sludge aside from saving coagulant materially assists in producing uniform sludge moisture, minimum alkalinity of this moisture and uniform coagulant dosing, sludge feeding and filter yield conditions common to waste activated sludge filtration. The floc produced is quite coarse and easy to drain with proper filter construction and installation.

Conclusion

The important factors relating to volatile matter, sludge moisture and natural reagents contained therein, do not explain all the discrepancies in coagulant doses and filter yields all over the North American continent, but they do explain the major portion of these discrepancies and narrow the field to where the influence of the remaining factors listed should be easier to track down through proper study and listing. Obviously the influence of the basic factors responsible for material differences in sludge behavior can be conducted with a greater degree of accuracy and speed with properly conducted Buechner filter tests. In such studies it is important to remember that even with excellent sludge uniformity conditions and uniform laboratory coagulation, the curdled aggregates vary widely in size and cannot be caused to pack into two simultaneously or consecutively produced filter cakes from the same sludge sample with identical void spacing. Some variations in filtration rates at identical pressures are therefore to be expected. Sludges from entirely different plants may for the same reason show even greater variations.

The basic factors listed indicate a wide field for further study. Whereas most industrial filtration theories and problems are chiefly concerned with the influence of the void fraction (moisture volume) related to solid or sludge compressibility, similar investigations of sewage sludges are also materially concerned with what happens to be contained in solution in the void fraction and its effects on coagulant addition and all the other factors.

The sludge behavior discovered through proper laboratory testing can then be compared with the actual behavior of the same sludges in the vacuum filter. Undoubtedly no small portion of the discrepancies found will be due to construction, installation and operation of the entire vacuum filter layout. My own observations convince me that many of these discrepancies arise from the type and condition of filter cloth used, improper piping between sludge coagulation tanks and filters, improper mixing of sludge and coagulant, and filter construction which prohibits rapid draining of coarsely coagulated sludges at any desired sludge level in the filter and proper distribution of the inflowing sludge through the filter bath.

In the absence of reliable uniform sludge conditions in the plant, the use of too many automatic control devices to secure uniform mechanical operation by a sequence of these devices starting at a constant sludge level in the filter can confuse an operator. Important additional uniformity conditions are required with continuous heat drying or incineration of the filter cake and the entire consecutive series of uniformity conditions start at this end of the plant and not at the filter. In relatively small plants variation in sludge level, dosing and number of filters operating are quite essential to meet these conditions. In all cases correct laboratory control, intelligent operation and supervision are most essential and sludge of reliable uniformity is of more value to an operator than several automatic mechanical controls.

As coagulant is absolutely essential to vacuum filter operation, coagulant feed should be always visible at some place near its place of addition to the sludge and the feeding equipment should be quickly accessible. Any alarm or signal notifying an operator that such coagulant feed has accidentally ceased to flow is equally as important as a low level alarm in the coagulant supply tank.

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Discussion

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To those who read Mr. Genter's analysis of the engineering factors relating to the construction, installation and operation of continuous vacuum filters for the dewatering of sewage sludges, it will be apparent that a broad well-paved road for further practical research has been constructed. The sign posts are many, and if the reader follows them a network of connecting highways will open before him. Here appears to be the first attempt at coordinating the general mathematical principles of sludge filtration and actual practice without resorting to theoretical calculations, which after all are of little or no interest to the filter operator.

The author's discussion of sludge solids compressibility deserves close scrutiny. In simple language the dewatering process of sewage solids is explained from their entrance into settling tanks to their final disposal. Solids compressibility and the author's accompanying discussion of capillary flow go a long way in explaining the effects of sludge coagulation and filtration, and therefore in giving the filter operator a clearly focused picture of vacuum filter performance.

The factors influencing sludge filtration as discussed by the author are so many that obviously no detailed discussion is practical. On a few of these factors I will, however, pass comment.

The value of Buchner funnel tests has been emphasized for some years as a control of filter operation. Many filter plants under our surveillance have set up such funnels for the operators in the filter room, rather than depending on remote laboratory control. Failure to use cake thicknesses on the funnels comparable with that obtained from the filter drums, and differences arising in the conditioning of the sludge, explain, as pointed out by Mr. Genter, most of the discrepancies reported in the past. There is, as he says, a decided difference between uniformly coagulated sludge and the homogeneous sludge often obtained in hand mixing.

That the author devotes considerable space to proper sludge coagulation is proper. My own experiences checks in particular the following points which he stresses:

1. Overdosing with ferric chloride causes resistance to free filtration, or in other words, sludge can be over-conditioned with chemicals as well as under-conditioned. Frequently an increase of the chemical dosage is the worst thing the filter operator could do.
2. Flash mix should be practiced if ferric chloride is used alone as a coagulant, but longer mixing is required when lime is also added.
3. The mechanical stirring of sludge with chemicals is superior to using compressed air.
4. Sludge can be too thick for conditioning, i.e. have too high a solids content.
5. Long feed pipes for coagulated sludge should be avoided. It might be added that the practice of pumping coagulated sludge to filter vats should be discarded in favor of short gravity feed.
6. Present-day filter vat agitators cause scouring of conditioned sludge from the drum and in many cases they might better be shut off or removed from the vats. What is needed is a method for better distribution of the sludge along the length of the drums.
7. Coagulated sludge may actually be too coarse for satisfactory filtration. In other words, mixing can be too well done for present-day filters.
8. Uniformity in character of raw, digested, or elutriated sludge for chemical coagulation is certainly a long step toward successful conditioning.

Figure 8 in the author's paper, showing the horsepower required at different vacuum gage readings for various filter areas, should be of interest to designers and operators. Some designers have failed to provide the proper sizes of vacuum pumps for average conditions, and operators have failed to run filters at their most economical gage readings.

The author's statement that compressibility of sludge solids is a function of the percentage of organic matter present and that sludges high in volatile solids are more difficult to filter, other things being equal, is probably true in most instances. However, might not the report of one Connecticut operator be correct that sludge of a high mineral content fails to coagulate properly, and that the cake under such circumstances slides off the drum because of the high grit content of the mass? Or is this the result of too high a total solids content?

I am still of the opinion that digestion of primary solids prior to filtration produces the better over-all conditions unless industrial wastes affect digestion or the plant is in the Big League class. Without direct discussion of this subject, the author's paper leans to this belief by emphasizing the advantage to the filter operator of uniform sludge. Uniform raw primary sludge is a rarity even with storage facilities; yet reasonably uniform sludges are obtained at plants digesting the solids. At least the change in filtering characteristics is more gradual and remedial measures can be taken before serious operating difficulties are encountered. Elutriation of digested sludge produces further uniformity and has much to recommend it for the larger plants. George H. Craemer, superintendent of sewage treatment in Hartford, in a paper presented last month before the New England Sewage Works Association has ably recited the beneficial results of elutriation at his plant, and has given useful operating data on the process.

An attempt to obtain the last hour from filter cloths is poor practice. If the filter operator will but compute the additional chemicals consumed for filtering sludge with plugged cloths, the economy of providing new filtering medium becomes apparent.

The selection of the form of ferric chloride to use in sludge coagulation frequently confronts the operator. Each plant operator should decide between the lump, anhydrous or liquid form depending on available storage space, mixing facilities, nearness to transportation yards, delivery charges, quantities used and the price per pound of available ferric chloride.

With raw primary sludge filtration, pre-chlorination of the raw sewage during the warm months can be of material aid to filtration by maintaining the sewage solids in a fresher condition. At one plant employing batch mix, the addition of one pound of ordinary chloride of lime to each 600-gallon batch of sludge has reduced odors in the filter room to a remarkable degree.

Rags in conditioning tanks, pipe lines, and filter vats have been and will continue to be an operating problem at plants handling raw sludge, until designers make provision for secondary screening. Even with shredders, stringy material enters the sludge, and comminutors, unless kept in first class condition, may also pass material which will clog and entwine around sludge stirring mechanisms. A small hand-cleaned screen at the entrance to the conditioning tanks is all that is generally needed, although at Chicago I noted the use of mechanically cleaned screens for the sludge prior to conditioning to prevent this trouble.

As with most sewage plant processes, the provision of flexibility in the design cannot be overstressed. Thought should be given to the nature and amounts of industrial wastes and the age of the sewage, as these may be a benefit or detriment. For example, at two plants in my state, not five miles apart (both handling raw primary sludge) the ferric chloride dose at one averages only 0.5 per cent on a dry solids basis and about 6 per cent calcium oxide, while at the other plant about 5½ per cent ferric chloride and 13 per cent calcium oxide are required. The sludges at these plants are of an entirely different character because of differences in the sewerage systems and in the nature of the wastes they collect.

The problems of sludge filtration are many and as plants operating under different conditions have been built, these problems have become magnified and of considerable economic importance. Further study is needed to broaden our knowledge of vacuum filter practice under the operating conditions afforded by existing plants. The major objectives that should be considered in such a study are:

1. Improvements in the design of vacuum filters and their appurtenances to handle the specific problems of sewage sludge dewatering rather than continuing our struggles with machines developed primarily to handle industrial materials of entirely different character.
2. To serve as a clearing house for practical helps on filtering problems at existing plants.
3. To foster and engage, insofar as possible, in research on sludge conditioning, coagulants, filter cloths and the many other factors influencing filtration rates and filter performance.

In Mr. Genter's splendid paper can be found the guide posts—results are bound to ensue!

Stream Pollution

THE NATURAL PURIFICATION OF RIVER MUDS AND POLLUTIONAL SEDIMENTS *

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VI. Potential Oxygen Demand Satisfied by Anaerobic Decomposition

It has been suggested before, in this series of papers, that the transfer of suspended pollutional substances to the bottom of receiving waters may reduce the over-all oxygen demand that would be exerted by them if they remained in suspension. Anaerobic as well as aerobic forces bring about the destruction of organic matter in the benthal environment, and the potential oxygen demand of river muds and pollutional sediments is satisfied, without withdrawing oxygen from the supernatant water, in proportion to the amount of anaerobic activity to which they are subjected. So far as the regimen of the receiving water is concerned, therefore, the transfer of pollutional matter to the bottom may, by impounding the oxygen demand at the stream bottom and there destroying a substantial portion of the potential demand by anaerobic activity, provide a general benefit in terms of reduced over-all oxygen requirements and a specific benefit during periods of low flow and ice cover. On the other hand, the local concentration of benthally decomposing organic matter and its accumulation in the absence of scour may intensify the demand for oxygen during the warm seasons of the year to such degree as to (1) offset the reduction of demand by anaerobic decomposition and (2) raise temporarily the oxygen requirements far above those of the pollutional substances that are in normal suspension in the receiving water.

Oxygen Demand Balance.—How important the reduction in potential oxygen demand can become is indicated by the results obtained in the authors' studies on the effect of sludge depth upon the rate of decomposition (see Section III of this series of papers). Depending upon circumstances the oxygen demand of benthal deposits may be aligned as follows:

U = the ultimate aerobic oxygen demand of the organic matter in the deposit;

B = that portion of U actually exerted during benthal decomposition;

* This is the third and concluding group in a series of papers on this subject. The first group appeared in the March, 1941, issue of *This Journal*, pp. 270 to 307, and contained the following discussions: I. Benthal Decomposition—General Concepts; II. Rates of Benthal Decomposition; and III. Effect of Sludge Depth upon Rate of Decomposition. The second group was printed in the July, 1941, issue of *This Journal*, pp. 756 to 779, and added the following discussions: IV. Effect of Sludge Temperature upon Rate of Decomposition; and V. Changes in Nitrogen, Iron, and Fuel Value of Decomposing Bottom Deposits.

N = the oxygen equivalent of the nitrogen compounds released to the supernatant water;
R = the residual oxygen demand at the termination of benthal decomposition; and
A = the oxygen-demand equivalent of methane and hydrogen released by anaerobic decomposition.

These demands, or their equivalents, are equated as follows:

$$U - R = B + N + A. \qquad (6)^*$$

Here the loss of oxygen demand during the period of benthal decomposition $(U - R)$ is accounted for by the measured benthal demand (B), the demand of the ammonia (N) and other oxidizable nitrogeneous substances (unknown but certainly small) released to the water washing the deposits, and by the oxygen equivalent of the methane and hydrogen escaping as

TABLE XVI.—*Observed and Calculated Oxygen Demands of Benthally Decomposing Sludge of Varying Depths and of Anaerobically Decomposing Sludge*

	Benthal Decomposition for 450 Days in Carboy No.					Anaerobic Decomposition for 495 Days
	I	II	III	IV	V	
Mean Depth—cm.	10.2	4.75	2.55	1.42	1.42	11.3
Volatile Matter, Initial—kg. per sq. m.	3.77	1.38	0.513	0.188	0.188	2.69
a. When oxygen demands are expressed in grams per kg. of volatile solids initially present, the oxygen demand at the start (U) being 818 + 13 (immediate demand) = 831.						
Oxygen Demand						
Observed Residual(1)—(R)	166	149	138	53	65	472
Calculated Overall—$(U - R)$	665	682	693	778	766	359
Observed Benthal(2)—(B)	169	274	400	677	635	—
Calculated Ultimate Benthal(2)—(B')	196	309	447	758	710	—
Calculated Anaerobic Equivalent(3)	496	408	293	101	131	—
Observed Ammonia Equivalent(4)—(N)	145	95	75	52	51	0
Calculated Combustible Gas Equivalent(5)—(A)	351	313	218	49	80	359
b. When oxygen demands are expressed as percentages of the demand at the start (100 per cent)						
Observed Residual—(R)	19.9	18.0	16.7	6.4	7.8	56.7
Observed Benthal—(B)	20.4	33.0	48.2	81.5	76.5	—
Calculated Ultimate Benthal—(B')	23.6	37.2	53.8	91.5	85.6	—
Observed Ammonia—(N)	17.4	11.4	9.1	6.3	6.2	—
Calculated Gas—(A)	42.3	37.6	26.0	5.8	9.5	43.3
Calculated Residual—(R')(6)	16.7	13.8	11.1	−3.6	−1.3	56.7

(1) See Table IX.
(2) See Tables VI and VII.
(3) $U - R - B$ includes soluble products leaching into water.
(4) $NH_3 + 2\,O_2 \rightarrow HNO_3 + H_2O$.
(5) $U - R - B - N$.
(6) $R' = U - B' - N - A$.

* Equations 1 to 5 appear in Sections II, III, and IV of this series of papers.

gases from the deposits. Equation (6) implies that the ultimate end products of complete aerobic stabilization and those of the aerobic phase of benthal decomposition are identical. While there is no direct proof of this, there is no reason to believe that any serious error is introduced by the assumption.

Observed Results.—A balance can be struck for the observed oxygen demands in accordance with equation (6). The results obtained in the authors' studies are summarized in Table XVI * and illustrated in Fig. 18.* For purposes of comparison, pertinent values obtained by subjecting the sludges to fully anaerobic decomposition are included in Table XVI.

Benthal decomposition was followed for 450 days and anaerobic decomposition for 495 days. These periods are so long that it seems safe to assume that, at their end, anaerobic decomposition was essentially at

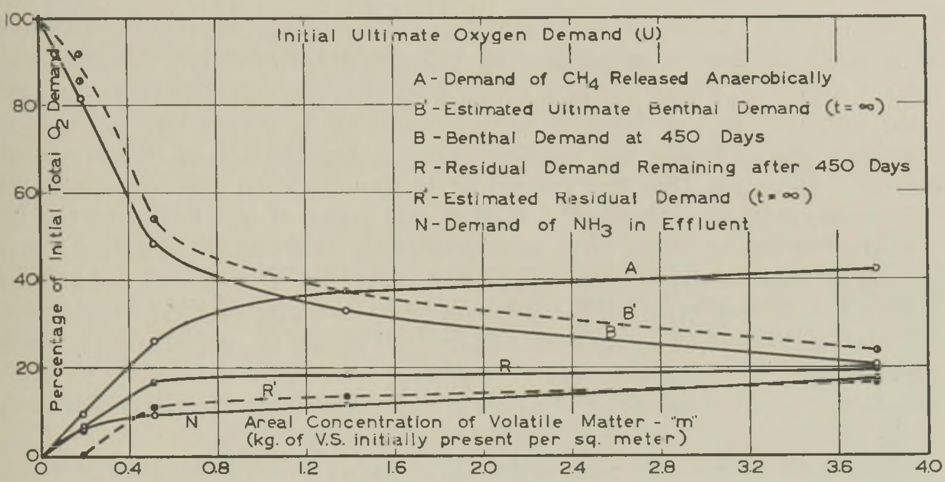

FIG. 18.—Oxygen demand balance showing the percentage of the initial, potential oxygen demand accounted for (1) by benthal oxygen requirements, (2) by oxidation of ammonia released to the supernatant water, (3) by release of combustible gases produced by anaerobic decomposition, and (4) by the residual demand remaining at the end of benthal decomposition.

a standstill and a nitrifying flora had long become established within the surface zone of the benthal samples and so made it impossible for additional quantities of gas (A) or ammonia (N) respectively to escape from the deposits. The values for A and N, therefore, may be assumed to have become constant after the lapse of 450 days. Benthal oxygen demand, B, on the other hand, should be expected to continue active and to increase at the expense of the residual demand, R. Estimates of the ultimate benthal demand, $B' = L$ (Table VII, Section III), and the corresponding ultimate residual demand, R', based upon the retardant curve of best fit, have been added to Fig. 18. For the two shallow depths (carboys IV and V), Table XVI shows the calculated values of R' to be negative ($-$ 3.6 and $-$ 1.3 per cent respectively), but this discrepancy is undoubtedly due to the poor precision attainable in measuring the ammonia released by

* Tables I to XV and Figs. 1 to 17 are found in Sections I to V of this series of papers.

these deposits. It is probable, however, that the ultimate residual demand of such thin deposits approaches close to zero. The curve for R' has, therefore, been so drawn in Fig. 18.

It is possible to fit exponential curves to the observed and calculated percentages of oxygen demand as follows:

Percentage Demand	*Equation*	
Observed benthal	$B = 19.2 + 80.8\, e^{-1.14m}$,	(6*a*)
Ultimate benthal	$B' = 20.2 + 79.8\, e^{-1.14m}$,	(6*b*)
Observed residual	$R = 18.0\,(1 - e^{-1.14m})$,	(6*c*)
Ultimate residual	$R' = 17.0\,(1 - e^{-1.14m})$,	(6*d*)
Ammonia equivalent	$N = 18.3\,(1 - e^{-1.14m})$,	(6*e*)
Combustible gas equivalent	$A = 44.5\,(1 - e^{-1.14m})$.	(6*f*)

Here e is the Naperian base of logarithms and m is the areal concentration of volatile matter in kilograms of volatile solids initially present per square meter of sludge surface. The relations are empirical and strictly valid only within the range of values tested ($m = 0$ to 4 kg. per sq.m.). Equation (6*b*) differs from equation (3*c*) in Section III of this series of papers. Equation (3*c*) was chosen to fit the observed data regardless of the rationale of the situation. Within the range of observations, the fit obtained is better than that resulting from the use of equation (6*b*). Equation (6*b*), however, makes allowance for the fact that in very deep deposits, *i.e.*, well beyond the range of observations, benthal oxygen demand must approach a constant value equal to the oxygen demand of the end products of anaerobic decomposition. A shift must be made from equation (3*c*) to equation (6*b*) when a wider mathematical generalization of the processes of benthal decomposition is contemplated.

The most important conclusion to be drawn from these observations is that deposits containing in excess of about one kilogram of volatile solids per square meter will exert a benthal oxygen demand less than half the potential requirements of the organic matter, provided that the sediment is not gas-lifted or resuspended by water movements in the course of its life. Most of the remaining potential demand will be released to the atmosphere in the form of marsh gas.

VII. Effect of Inorganic Admixtures upon Rate of Decomposition

Surface wash and storm drainage together with soil erosion normally carry appreciable amounts of inorganic and, ordinarily, inert matter into receiving waters. River muds and pollutional sediments, therefore, may be expected to contain considerably larger fractions of non-decomposable solids than are normally included in fresh sewage sludge (see Table I, Section I). To what extent these admixed substances influence the course of decomposition is of considerable interest.

Experimental Procedures and Results.—To determine the effect of inorganic admixtures upon the rate of decomposition, clay and sesquioxides of iron and aluminum (Fe_2O_3 and Al_2O_3) were added to sewage sludge in varying proportions and the resulting mixtures incubated and observed. To simplify operations, the experiments were confined to anaerobic digestion of the mixtures.

TABLE XVII.—*Composition of Sewage Sludge Employed in Clay-Sludge Mixtures*

	Fresh Sludge	Digested Sludge
Total Solids—per cent of total wet weight	2.71	3.58
Volatile Solids—per cent of dry solids	74.5	67.9
Total Organic Nitrogen—grams per kg. of volatile solids	43.0	46.2
Ammonia Nitrogen—grams per kg. of volatile solids	4.0	8.1
Organic Carbon—grams per kg. of volatile solids	548	540
B.O.D.—grams per kg. of volatile solids		
5-day, 20° C.	314	265
Ultimate	487	665
Reaction velocity, k_u at 20° C.(1)	0.200	0.0998
Iron as Fe_2O_3—grams per kg. of volatile solids	49.6	57.3
Aluminum as Al_2O_3—grams per kg. of volatile solids	14.9	15.5

(1) This value is 2.303 times the magnitude of the reaction velocity constant as calculated by Phelps and others.

Two series of four mixtures were prepared. In the first series (flasks A to D), clay was mixed in varying proportions with comminuted fresh sludge collected from the settling compartments of the Imhoff tanks at Fitchburg, Mass. In the second series (flasks E to H), digested sludge drawn from the heated separate tanks at Leominster, Mass., was added to the clay-sludge mixtures for seeding purposes. Analyses of the fresh and digested sludges are shown in Table XVII, and the composition of the mixtures is given in Table XVIII. The clay was prepared by blending fire clay, kaolin, alumina and ferric oxide to give a mixture containing

TABLE XVIII.—*Composition of Clay-Sludge Mixtures*

	Unseeded Mixture				Seeded Mixture			
	A	B	C	D	E	F	G	H
Total Solids—per cent of wet mixture	2.71	6.37	14.5	28.9	3.58	7.62	17.2	33.1
Volatile Solids								
Per cent of total	74.5	30.0	12.0	5.0	67.9	30.0	12.0	5.0
Grams	50.4	50.4	50.4	50.4	60.7	60.7	60.7	60.7
Specific Gravity	1.005	1.03	1.09	1.21	1.009	1.04	1.10	1.24
Total Gas—l. per kg. of fresh volatile solids*	603	459	320	159	547	460	480	435
Methane—per cent of total	65.7	65.1	63.0	61.9	69.9	71.7	68.8	66.3
Carbon Dioxide—per cent of total	34.3	34.9	37.0	38.1	30.1	28.3	31.2	33.7
Loss of Carbon†—per cent of initial	58.8	44.8	31.2	15.5	54.3	45.6	47.6	43.2
Initial Organic Carbon—per cent of dry weight	41.0	16.4	6.6	2.74	36.6	15.5	6.47	2.70

* At 0° C. and 760 mm. pressure in 140 days.
† In 140 days.

4.46 per cent of Fe_2O_3, 28.1 per cent of Al_2O_3 and 67.4 per cent of SiO_2. Clay and kaolin were washed in hydrochloric acid, rinsed, dried, and pulverized prior to mixing, in order to exclude alkaline and alkaline earth metals. Digested sludge was added to the seeded mixtures in the propor-

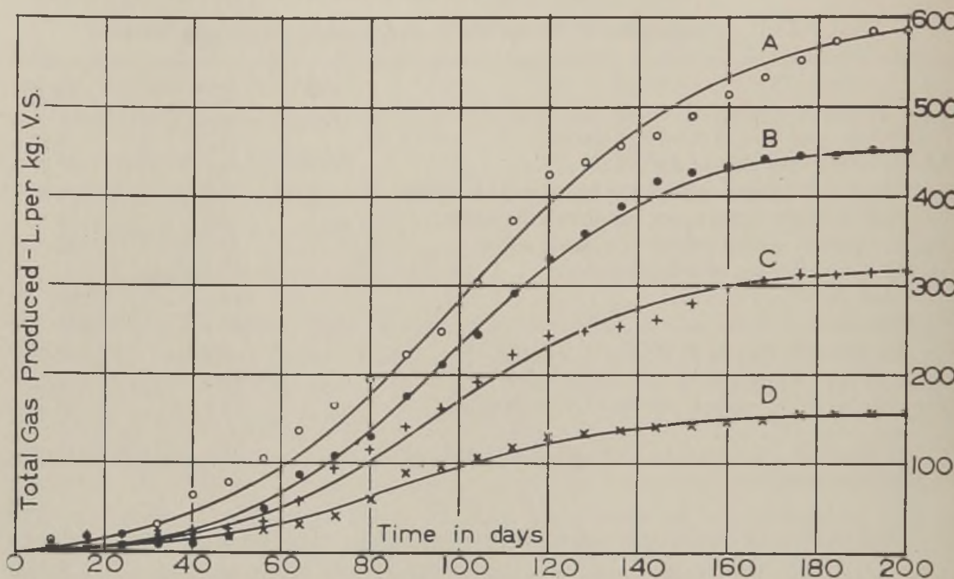

FIG. 19.—Cumulative gas production of unseeded mixtures of fresh sewage solids and clay. The curves are drawn from fitted autocatalytic unimolecular equations. The temperature of incubation was 25° C., and the percentage of volatile solids in the mixtures was: $A = 74.5$; $B = 30.0$; $C = 12.0$; and $D = 5.0$.

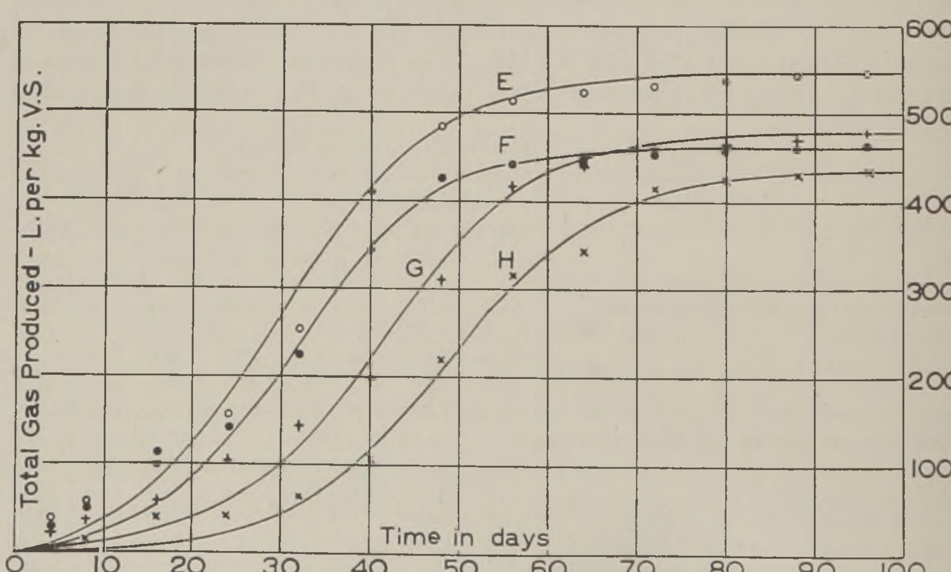

FIG. 20.—Cumulative gas production of seeded mixtures of fresh sewage solids and clay. The curves are drawn from fitted autocatalytic unimolecular equations. The temperature of incubation was 25° C., and the percentage of volatile solids in the mixtures was: $E = 67.9$; $F = 30.0$; $G = 12.0$; and $H = 5.0$.

tion of one kilogram of digested to two kilograms of fresh volatile matter. To cover as wide a range of admixtures as possible, equal amounts of sludge were placed in the flasks in each of the two series and clay was added to them in approximately geometric progression so as to obtain a content of volatile solids varying from 5 per cent of the total solids to the percentage occurring in the sludge itself (about 70 per cent). The mixtures contained from 2.7 to 33.1 per cent of total solids and possessed specific gravities varying from 1.005 to 1.24. This probably covers the range of conditions ordinarily encountered in sludge banks that are formed in polluted waterways.

The flasks were incubated anaerobically in a water bath at 25° C., and the gases of decomposition were collected, measured, and analyzed. In addition to methane and carbon dioxide, small amounts of hydrogen were produced at times by those mixtures that contained the lowest proportions of volatile solids, *i.e.*, the highest admixture of clay. Table XVIII includes figures on the composition of the gas, and Figs. 19 and 20 trace the time-rates of gas evolution. The pH values of the decomposing mixtures were measured at frequent intervals by means of a glass electrode, and the results obtained are recorded in Table XIX.

TABLE XIX.—*pH Values of Decomposing Clay-Sludge Mixtures*

	Unseeded Mixture				Seeded Mixture			
	A	B	C	D	E	F	G	H
Volatile Solids—per cent	74.5	30.0	12.0	5.0	67.9	30.0	12.0	5.0
Time—days								
Initial	5.3	5.2	5.3	5.2	6.8	6.5	6.4	6.1
11	5.1	5.3	5.2	5.4	6.6	6.3	5.7	5.4
30	5.3	5.2	5.3	5.5	7.5	7.1	6.6	5.5
58	6.6	5.4	6.3	6.5	7.6	7.5	7.7	6.7
89	6.6	6.3	6.5	6.1	7.4	7.4	7.0	6.8
114	7.2	6.9	6.8	6.4	7.4	7.7	7.4	7.3
Final	7.2	6.9	6.8	6.8	7.4	7.6	7.4	7.3

The seeded samples liberated no measurable amounts of gas after a hundred days of digestion, but, to make sure, incubation was continued to 140 days. The unseeded mixtures yielded small volumes of gas for about 225 days and were held in the water bath for 360 days.

Autocatalytic Formulation of Anaerobic Decomposition.—Cumulative plotting of gas yields for the two series of mixtures (Figs. 19 and 20) suggests that the progress of breakdown of these mixtures, like that of sewage sludge alone, can be represented by autocatalytic unimolecular equations as suggested by Fair and Moore (22).* This formulation is premised on the assumption that the rate of decomposition—as measured here by gasification—is proportional, not only to the amount of organic

* References 1 to 12 are appended to Sections I to III of this series of papers; references 13 to 21 to Sections IV and V.

matter remaining to be decomposed, but also to an intensity factor that is itself a function of the amount of organic matter that has already undergone decomposition. That anaerobic decomposition should proceed at a rate proportional to the amount of material on hand is in accord with general biochemical experience. If this constituted the sole control, the reaction would be unimolecular, as shown previously in this series of papers. That it is not, appears to be related to the initial acid reaction and limited buffering capacity of digesting sludge as well as to the initial scarcity of methane-producing bacteria. Fresh sludge, unless it is adequately buffered and seeded, therefore, will not produce gas at maximum rate, in spite of the abundance of organic material amenable to digestion. Consequently, the rate of gasification must accelerate during the breaking-in period when organic acids are being eliminated and a population of methane-producing organisms is being created.

Mathematically, this behavior of anaerobically digesting material may be approximated by the inclusion in the differential relationship of an intensity factor that is proportional to the amount of material that has been decomposed. The resulting equation is:

$$\frac{dG}{dt} = k_a G(G_a - G), \tag{7}$$

where $\frac{dG}{dt}$ = the rate of gasification at time t;

G = the amount of gas produced from the start of decomposition;

G_a = the total gas that can potentially be released from the deposit; and

k_a = the proportionality factor.

In a sense, there is no such thing as strictly fresh sludge because sewage solids have almost always undergone some decomposition and gasification before collection and a small population of methane-producing bacteria is already busily at work on them. Mathematically, this means that the ultimate volume of gas that can be collected will not quite equal G_a by a small amount, G_s. This is equivalent to saying that the initial rate of gasification that is observed experimentally must be finite. Figure 21 has been drawn to explain existing relations.

Equation (7) may be integrated—making use of the condition that for $t = 0$, $G_t = 0$, or $G = G_s$—to yield the following expression for the autocatalytic equation in its simplest form:

$$G_t = \frac{G_a}{1 + \frac{G_u}{G_s} e^{-k_a G_a t}} - G_s. \tag{8}$$

Here $G_t = G - G_s$ = the amount of gas collected in time t;

$G_u = G_a - G_s$ = the ultimate amount of gas that can actually be produced; and

e = the Naperian base of logarithms.

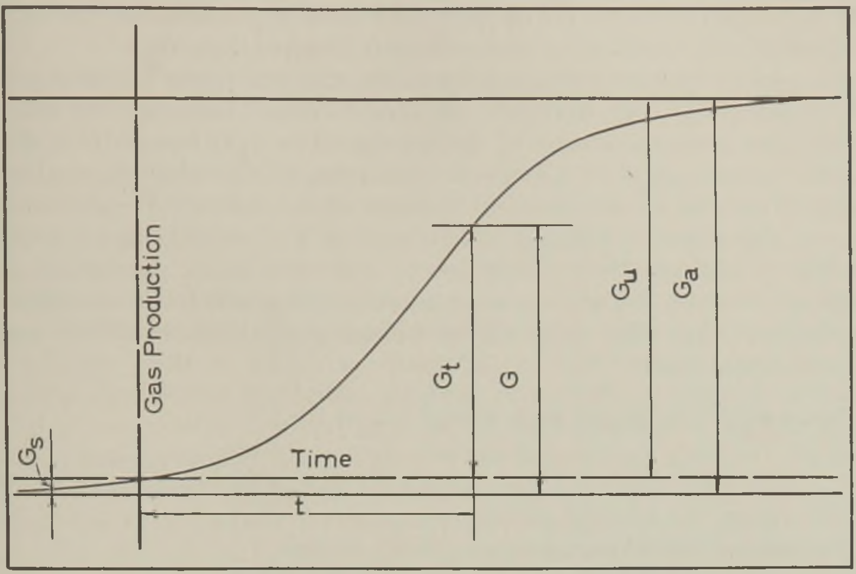

FIG. 21.—Significance of notation employed in developing the autocatalytic unimolecular equation for the course of gas production in the anaerobic digestion of mixtures of sludge and clay.

In equation (8) the coefficient of t, k_aG_a, is the reaction velocity constant of the autocatalytic equation. It possesses the inverse dimension of time. Consequently the numerical value of k_aG_a depends upon the unit of time employed. As shown in the Appendix to this Section, equation (8) may be fitted to experimental data by a least squares procedure based upon equation (7) as well as (8). To avoid the laborious computations of this procedure, graphical fitting may be resorted to, with reasonable success. Least squares treatment of the authors' experimental observations underlies the curves of Figs. 19 and 20. An excellent degree of agreement between observed and fitted values is seen to obtain. The calculated parameters of equation (8) are listed in Table XX, together

TABLE XX.—*Autocatalytic Parameters of Anaerobic Decomposition of Clay-Sludge Mixtures*

	Unseeded Mixture				Seeded Mixture			
	A	B	C	D	E	F	G	H
Volatile Solids—per cent	74.5	30.0	12.0	5.0	67.9	30.0	12.0	5.0
$G_u^* - G_a = G_s$	603	459	320	159	547	460	480	435
G_a^*	618	466	325	163	566	469	484	437
$k_a \times 10^6$	58.3	92.0	133	255	200	271	238	260
G_s^*	15	7	5	4	19	9	4	2
k_aG_a per day	0.0361	0.0428	0.0432	0.0416	0.113	0.127	0.116	0.115
Days to reach								
50 per cent completion	103	98	97	89	30	31	41	49
90 per cent completion	164	150	148	142	50	49	60	68
99 per cent completion	230	206	203	199	71	67	81	89

* Liters per kg. of fresh volatile solids.

with the computed number of days that have elapsed before gasification has been 50, 90, and 99 per cent completed—equations (8*a*).

By generalizing the observed results, the mathematical parameters shed considerable light upon the manner in which the admixed clay and sesquioxides alter the course of sludge digestion. Although G_s is dimensionally the same as G_t, it has no corresponding measurable physical entity but exists only as a mathematical measure of the initial lag or acceleration phase of digestion. A better understanding of G_s is obtained by solving equation (8) for the time t in which G_t reaches a given percentage of its ultimate value G_u. The following relations, derived from equation (8), express the times that must elapse before gasification is 50, 90 and 99 per cent completed.

Decomposition 50 per cent completed in time

$$t = \frac{1}{k_a G_a} \log_e \frac{G_a + G_s}{G_s}, \qquad (8a_1)$$

Decomposition 90 per cent completed in time

$$t = \frac{1}{k_a G_a} \log_e \frac{9G_a + G_s}{G_s}, \qquad (8a_2)$$

Decomposition 99 per cent completed in time

$$t = \frac{1}{k_a G_a} \log_e \frac{99G_a + G_s}{G_s}. \qquad (8a_3)$$

It appears, therefore, that for a given reaction velocity k_aG_a the time of digestion depends largely upon the value of G_s.

Parenthetically, equations (7) and (8) express the autocatalytic reaction in its simplest form for the purpose at hand. The common expression for this reaction (22) in differential form is as follows:

$$dG_t = [k_1(G_u - G_t) + k_2G_t(G_u - G_t)]dt, \qquad (7a)$$

where k_1 and k_2 are reaction velocity constants. This equation may be transformed into equation (7) by use of the following relationships:

$$k_1 = k_2G_s, \qquad k_2 = k_a \qquad \text{and} \qquad G_u - G_t = G_a - G.$$

The advantage gained by this transformation is twofold: (1) it results in a formulation containing only the fundamental reaction velocity constant ($k_a = k_2$); and (2) it simplifies the integrated expression. The resulting equation (8) possesses just one exponential term and makes possible the direct application of the least squares method in the evaluation of the constants of the equation.

Discussion of Results.—Examination of Tables XIX and XX, and Figs. 19 and 20 shows the following:

1. Addition of inorganic substances to fresh sewage solids reduced the yield of gas, G_a or G_u, very markedly but increased the reaction velocity, k_aG_a, slightly. As a result, the time required to complete certain propor-

tions of the gas yield was diminished. The pH values were low to begin with but did approach values favorable to gasification in the long run.

2. Addition of inorganic substances to seeded sewage solids reduced but slightly the yield of gas, G_a or G_u, and did not affect the reaction velocity, k_aG_a, significantly. As a result, the time required to complete certain proportions of the gas yield remained much the same. The pH values of the mixtures containing increasing amounts of clay were lowered measurably and lagged behind throughout the digestion period.

3. Compared with the unseeded clay-sludge mixtures, the seeded mixtures produced substantially more gas, G_a or G_u, at reaction velocities, k_aG_a, about three times as great and at higher pH values. Since "seeding" is a relative term to which no quantitative significance is attached, it may be assumed that the initial presence of previously digested substrate may alter the rate of reaction by a factor that may be as high as ten, as has been found for effectively seeded digesting sewage sludge. The time required to complete given percentages of gasification is conveniently reckoned in weeks for the seeded mixtures and in months for the unseeded ones.

4. The differences in volumes and rates of gasification, observed to exist in the seeded and unseeded mixtures and within the series of mixtures themselves, appear to be due, in part, to decreased mobility of interstitial fluids and organisms and to adsorption upon the enormous surfaces of the clay colloids of ammonium salts and other compounds that contribute to alkalinity and buffering properties. That some such inactivation of the buffering power of the seeding sludge did occur is evidenced by the decrease in the values of initial pH that was observed to take place with the addition of inorganic materials.

Changes in the Organic Carbon Content of Digesting Sludge-Clay Mixtures.—In a monumental study of the River Mersey by the Water Pollution Research Board of the Department of Scientific and Industrial Research of Great Britain, (23), a series of samples of mud from Stanlow Bank containing varying proportions of organic matter was analyzed prior and subsequent to storage under sea water at room temperature for a period of six to twelve months. In Fig. 22 are summarized the average results obtained for those samples that were stored twelve months in complete darkness. The per cent change in amount of organic carbon initially present, in the Mersey muds, is seen to pass from a gain at low concentrations of organic carbon to a loss at high concentrations when the concentration is expressed as a percentage of the total dry solids.

For purposes of comparison, the corresponding quantities obtained by the authors with unseeded clay-sludge mixtures, which represent more closely than the seeded mixtures the polluted muds of the River Mersey, have been plotted in Fig. 22 from the values included in Table XVIII. Inspection reveals a remarkable degree of continuity between the two series of tests in spite of dissimilar conditions of experiment and methods of chemical analysis. The British tests, lying above the zero line and recording a *gain* rather than a *loss* of organic carbon as a result of storage, indicate a synthesis associated with the fixation of inorganic carbon (broken bits of seashells, etc.) by the activities of autotrophic bacteria, which were believed to include among others iron and sulphur bacteria. The samples concerned in this phase of the British tests contained little organic carbon and were taken from regions remote from pollution, thus representing natural rather than heavily polluted river sediments. It should be noted in passing that the activities of autotrophic organisms are predicated upon the presence of dissolved oxygen and oxidized compounds such as nitrates and sulphates. This requirement was fulfilled in the British tests.

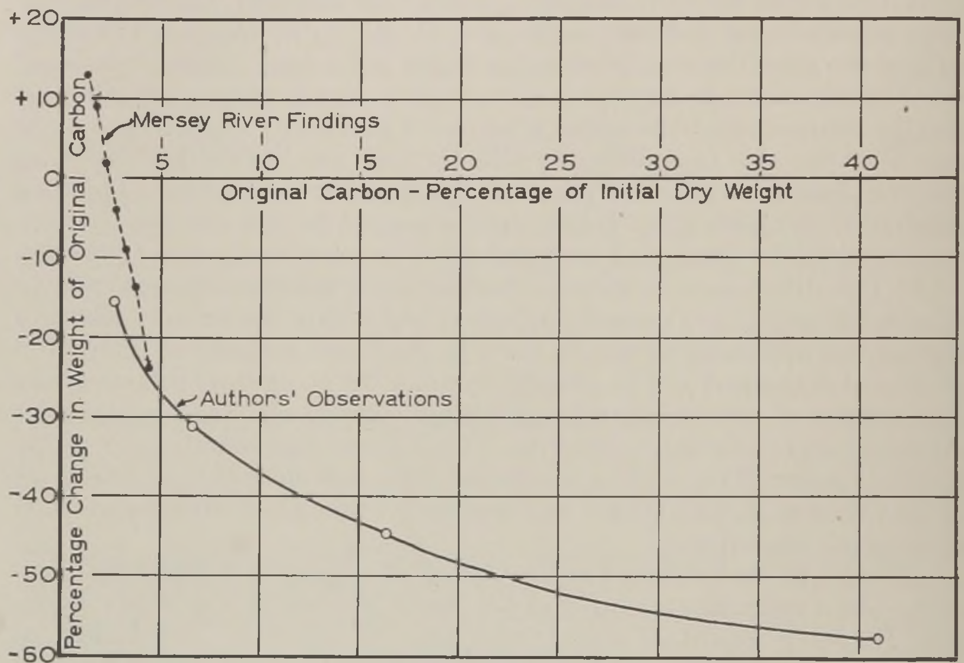

FIG. 22.—Percentage change during anaerobic decomposition in the weight of organic carbon contained in Mersey River muds and sludge-clay mixtures relative to the original carbon content of these deposits.

The conclusion may be reached that the rate of loss of organic carbon is greatest in deposits containing large amounts of such carbon compounds. As the initial concentration of organic carbon decreases, the percentage loss drops off until, at a concentration of about 1 to 2 per cent, no change is observed in a period of a year. If less than this critical amount of carbon is present in the mud and certain other conditions that favor the growth of autotrophic bacteria are realized, an actual increase in organic carbon to the equilibrium point will result. As a consequence, the content of organic matter in river muds and pollutional sediments is seen to approach a constant value at a rate depending upon the amount of organic material initially present. This rate is also affected by the colloidal properties of the mixtures, the adsorbing properties of the inorganic particles, the concentration of sesquioxides, and the extent to which these enter into complexes with the organic constituents, particularly the amino-acids and other albuminous materials. Finally it should be noted that the alteration of the physical environment by the addition of heavy minerals may impose limitations upon the course of digestion and materially lessen the rate and magnitude of decomposition.

VIII. Oxygen Demand of Pollutional Sediments in the Process of Accumulation—Continuous Deposition

The experimental work upon which this paper is based was conducted with deposits of established depth and composition that received no further accessions of decomposable matter by the settling upon the sludge surface of solids thrown out of suspension by the supernatant water. In practice, this simplified situation does occur but is not the most common one. As a rule, sludge banks are not laid down as a whole at one time but are built up gradually, a little each day, until the accumulated mass is shifted in position, carried away by floods, or otherwise released. Changing hydrological conditions may indeed resuspend and redeposit the sediments several times in the course of their existence within the critical reaches of receiving waters. In view of this situation, it becomes important to see if it is possible to develop, with the material at hand, ways and means for evaluating, even if indirectly, this aspect of the natural purification of river muds and pollutional sediments.

Mathematical Formulation of Oxygen Demand in Continuous Deposition.—Starting with a clean river bottom, the oxygen demand of the accumulating sediments is primarily a function of the quantity of organic matter laid down daily by the receiving water. If we simplify the problem by assuming that this increment, w, is uniform in quantity and structure, and that the temperature of the deposit remains unchanged, the instantaneous oxygen demand, dz/dt, exerted after any given lapse of time, t, must equal the sum of the instantaneous demands of each incremental layer of the deposit, or:

$$\frac{dz}{dt} = w \int \frac{dy}{dt}$$

and from equation (1d) of Section III of this series of papers:

$$dz = w \int \frac{kL}{(1 + at)^{k/a+1}}\, dt. \tag{9}$$

Here y = the oxygen demand exerted in time t;
L = the ultimate oxygen demand of the deposited materials;
k = the reaction velocity constant;
and a = the coefficient of retardation.

We have seen in Section III of this series of papers that the values of L, k, and a depend, in large measure, upon the areal concentration, m, of organic matter in the deposit, which in turn is a function of the daily increment of organic matter, w, and time, t. In equations (3a, b, c), these mathematical parameters of benthal oxygen demand have been related empirically to m, but their substitution in equation (9) is too cumbersome to be useful. Our purposes are served better if we assume that k and a

are constant—a reasonable assumption for all but extremely shallow layers of mud—and adduce the necessary generalization of L from equation (6b) by writing it in the following form:

$$L = L_f + L_b e^{-bm}, \qquad (6b')$$

where $L = B'$ = the ultimate oxygen demand of any layer of sludge;
L_f = that portion of the ultimate benthal oxygen demand exerted by very deep deposits and due essentially to the oxidation of products of anaerobic decomposition that are transported, or displaced, upwards into the surface zone. L_f is approximately equal to 20 per cent of the total initial B.O.D. (U).
$L_b = U - L_f$ = that portion of the ultimate benthal oxygen demand associated directly with aerobic decomposition.
b = a constant apparently possessing a value between 1 and 1.2 when m is expressed in kilograms per square meter.

If we envisage a linear relationship, $m = wt$, between areal concentration of volatile matter initially present, daily increment of volatile matter, and time, we may substitute this generalized value of m into equation (6b') and the resulting expression for L into equation (9). Integration then yields the following approximation, z/w, of the daily oxygen demand, per unit surface area and per unit increment of volatile matter, of a deposit that has accumulated organic solids and undergone decomposition during t days:

$$\frac{z}{w} = L_f[1 - (1 + at)^{-k/a}] + \frac{k}{bw + k} L_b[1 - e^{-(bw+k)t}]. \qquad (10)$$

The first term of this equation represents the basic, ever-present oxygen demand of the partially stabilized products of anaerobic decomposition contributed in time t. As time proceeds, or as deposits deepen, this term, as exemplified later, becomes increasingly important and may eventually constitute nearly the entire daily oxygen demand.

The second term of equation (10) represents the aerobic oxidation in time t of a fraction $[k \div (bw + k) < 1]$ of the other decomposable substances ($L_b = U - L_f$). As shown in the illustrative example, this term is important only for a short time after deposition begins and when the daily increment, w, is small. For these conditions, the areal concentration of decomposable solids on the floor of the receiving water is low and aerobic micro-organisms play a major part in the stabilization of the deposits.

In time, the daily oxygen demand attains a constant value z_m/w which is maintained so long as deposition is continued. The expression for this value is:

$$\frac{z_m}{w} = L_f + \frac{k}{bw + k} L_b. \qquad (10a)$$

At its maximum, therefore, benthal decomposition is destroying organic matter as fast as it is being thrown down. The deposit increases in depth by accumulation of the non-decomposable residues, but its content of organic matter remains unchanged. It is evident from equation (10*a*) that the maximum rate of oxygen demand approaches the ultimate demand, U, of a single day's increment of sludge when bw is small, *i.e.*, w itself is small, and z_m is approximately equal to $w(L_f + L_b) = wU$.

Equation (10*a*) can be simplified for approximate use: (1) by expressing L_f and L_b as fixed portions of the ultimate demand, U, (2) by assigning average values to b and k, and (3) by writing U in terms of the 5-day, first-stage B.O.D. of the deposited sediment. If the average daily rate of deposition of volatile solids is w kg. per sq. m. or w' lb. per acre, equation (10*a*) becomes:

$$F = 0.6 + \frac{2.4}{1 + 160w} = 0.6 + \frac{2.4}{1 + 0.02w'}. \tag{10b}$$

Here F is a factor by which the 5-day B.O.D. of the material deposited each day must be multiplied in order to find the maximum daily benthal oxygen demand of the accumulating sediment. If the 5-day B.O.D. is expressed in grams per kg. of volatile matter, Fw times the amount is the daily benthal oxygen demand in grams per sq. m. Similarly Fw' times the 5-day B.O.D. in lb. per lb. of volatile matter is the daily benthal demand in lb. per acre. The maximum value of F will be realized only after a considerable lapse of time. Short-term values, F_t, may be approximated for times, t, less than 365 days by means of the following empirical relationship:

$$F_t = F\sqrt{\frac{t}{365}} = 0.05F\sqrt{t}. \tag{10c}$$

For t equal to or greater than 365 days, no adjustment is necessary. The values of F and F_t are unaffected by temperature, and the benthal oxygen demand at temperatures other than 20° C. can be approximated by multiplying the 5-day, 20° C. B.O.D. of the daily increment of sediment by F or F_t together with the pertinent coefficient from the following schedule:

Temperature—°C.	5	10	15	20	25	30	35
Temperature—°F.	41	50	59	68	77	86	95
Coefficient—	0.45	0.60	0.79	1.00	1.23	1.47	1.71

The imposed load w or w' may be taken as the average rate of sludge accumulation (not necessarily constant) over the period of deposition provided that the monthly deviations from the average do not exceed $0.3w$ or $0.3w'$ respectively.

Sample Calculation.—The numerical significance of the various factors involved is best brought out by an example such as the following:

The solids suspended in a receiving water are deposited in a quiescent area. The ultimate oxygen demand (U) of these solids is 1000 grams per kilogram of volatile matter and the constants in equation (10) possess the following values: L_f = 20 per cent of 1000 = 200 grams per kg. of volatile solids; L_b = 1000 − 200 = 800 grams per kg. of volatile solids; k = 0.007 per day; a = 0.003 per day; k/a = 2.33; and b = 1.14 sq.m. per kg. of volatile solids. The temperature is assumed to be 20° C.

The daily oxygen demand exerted by each square meter of the deposit for various values of w and t can be calculated from equation (10) by direct substitution of the given constants but is found more quickly by employing Fig. 3 in Section II of this series of papers. The demands shown in Table XXI have been calculated for $w = 0.01$ and $w = 0.1$ kg. of volatile solids

TABLE XXI.—*Calculated Rates of Oxygen Demand and Percentages of Fully Aerobic Demands of Deposits Receiving Daily Increments of Volatile Solids of 0.01 and 0.1 Kilogram of Volatile Solids per Square Meter*

	Time in Days		
	10	100	∞
Rate of Oxygen Demand—grams per sq.m. per day			
$w = 0.01$: $w \times$ First term of equation (10)	0.14	0.91	2.00
$w \times$ Second term of equation (10)	0.51	2.56	3.04
Sum	0.65	3.47	5.04
$w = 0.1$: $w \times$ First term of equation (10)	1.36	9.14	20.00
$w \times$ Second term of equation (10)	3.25	4.62	4.62
Sum	4.61	13.76	24.62
Per Cent of Fully Aerobic Oxygen Demand			
$w = 0.01$	11.0	36.1	50.4
$w = 0.1$	7.9	14.3	24.6
Fully Aerobic Oxygen Demand			
y/w	587	963	1000

per square meter per day respectively when $t = 10$, 100 and an infinite number of days.

A single calculation will be shown here. For $w = 0.1$ and $t = 100$, substitution of the given values in equation (10) gives:

$$z = 0.1 \left\{ 200[1 - (1 + 0.3)^{-2.33}] + \frac{0.007}{0.114 + 0.007} 800[1 - e^{-(0.114+0.007)100}] \right\}.$$

Simplifying,

$$z = 0.1(91.4 + 46.2) = 13.76 \text{ grams per sq.m. per day.}$$

To use Fig. 3, find for $k/a = 2.33$ and $kt = 0.7$

$$y_f/wL_f = 0.455 \quad \text{and} \quad y_f = 0.455 \times 200 \times 0.1 = 9.1;$$

and for $k/a = \infty$ and $kt = (0.114 + 0.007)100 = 12.1$

$$y_b/wL_b = 1 \quad \text{and} \quad y_b = 1 \times 800 \times 0.1 = 80,$$

or

$$\frac{0.007}{0.114 + 0.07} 80 = \frac{0.56}{0.121} = 4.6.$$

Hence $z = 9.1 + 4.6 = 13.7$ grams per sq.m. per day.

The fully aerobic oxygen demand can be calculated from equation (2) in Section II of this series of papers as being $y/w = U[1 - (1 + at)^{-k/a}]$ for $U = 1000$ grams per kg. of volatile matter; $a = 0.08$ per day; and $k = 0.12$ per day; or it may be read from Fig. 3.

According to equation (10*b*), the maximum rate of benthal oxygen demand would equal F times the 5-day B.O.D. of the material deposited daily. For $w = 0.01$ grams per sq. m. daily: $F = 0.6 + 2.4 \div (1 + 160 \times 0.01) = 1.5$. If the 5-day, 20° B.O.D. of the daily accession of sediment is 340 grams per kg. of volatile solids, the maximum daily benthal demand will be $F \times 340 \times w = 1.5 \times 340 \times 0.01 = 5.1$ grams per sq. m. per day. This is in close agreement with the corresponding value (5.04) indicated in Table XXI.

Table XXI shows that continuous deposition reduces the rate of oxygen demand, as in other forms of benthal decomposition, materially below the rate of the fully aerobic oxygen demand that would be established if the solids remained suspended in water containing dissolved oxygen. This reduction is to be attributed (1) to the physical environment which restricts the rate of transfer of oxidizable products to the surface and (2) to the activity of anaerobic organisms in destroying the potential oxygen demand of the organic matter without drawing upon free oxygen reserves of the supernatant water to do so. Equilibrium between organic matter deposited and organic matter decomposed with which the maximum daily demand is associated * is attained only after a long lapse of time. It would appear, therefore, that a maximum rate of oxygen demand equal to the demand of the daily increment of organic matter would be a distinctly conservative engineering assumption to make, except (1) when deposits have accumulated during cold weather and begin suddenly to work as the stream warms up and (2) when sludge is gas-lifted into the supernatant water and there undergoes aerobic decomposition.

Summary of Parts VII to IX

The potential oxygen demand of the decomposable matter deposited on the floor of receiving waters is seldom exerted in full measure. As river muds and pollutional sediments grow in depth, anaerobic decomposition gains the whip hand and releases to the sludge-water interface only remnants of the oxygen-demanding substances originally accumulated. Deposits containing in excess of about a kilogram of volatile solids per square meter of surface, for example, may be expected to exert a benthal oxygen demand that is less than half the potential demand of the settleable solids discharged into the receiving water. If the deposits are gas-lifted, or otherwise resuspended in the supernatant water, however, the proportion may be greatly increased. Most of the oxygen demand that is dissipated by anaerobic decomposition is liberated to the atmosphere as marsh gas—a helpful Will-o'-the-wisp in the natural purification of river muds and pollutional sediments. A balance can be struck in which the sum of the benthal oxygen demand, the oxygen equivalent of the nitrogenous com-

* Equation (10*a*).

pounds released to the supernatant water, the oxygen equivalent of the combustible gases liberated to the atmosphere and the residual oxygen demand must be equal to the ultimate oxygen demand of all the materials laid down.

Much inert matter is included with the decomposable, organic substances that form river muds and pollutional sediments; how much, depends upon the physiography of the catchment area, the nature of the wastes produced, and the hydrology of the receiving water. Finely divided clay and similar colloidal solids adsorb ammonium salts and other compounds that contribute alkalinity and buffering properties to the decomposing deposits. This depresses pH values and reduces the yield of gas and with it, probably, the effectiveness of anaerobic activity. Measured in terms of organic carbon, decomposition is greatest in deposits that contain large amounts of carbon compounds. At low concentrations, little change takes place. As a rule, a more or less constant concentration of organic carbon seems to become established. Alteration of the physical environment associated with the formation of relatively dense and highly mineralized sediments appears to impose limitations on the course of sludge digestion and materially to lessen its rate and magnitude. The course traced by gas production is well fitted by an autocatalytic, unimolecular formulation.

The accumulation of deposits within a given reach of receiving water generally extends over a protracted period of time. It is possible, however, for sludge banks to be resuspended and shifted in place due to changing, often seasonal, hydrographic conditions. Fluctuating temperatures contribute to the complexity of the picture. The simple case of a constant rate of accumulation of structurally uniform, decomposable matter is amenable to approximate mathematical analysis. The generalization thereby established indicates that a reduced rate of oxygen demand accompanies the building up of deposits and that a maximum rate is reached in the course of time at which the rate of decomposition balances the rate of deposition. It follows that a maximum rate of oxygen demand equal to the demand of the daily increment of organic matter would be a safe engineering assumption under the conditions of sludge accumulation upon which the analysis is based.

General Conclusion

The natural purification of river muds and pollutional sediments is a complex phenomenon in which natural variations in hydrographic conditions, seasonal fluctuations in temperature, and other elements that are variable in time and cannot be formulated, except in statistical terms, add to the difficulties of engineers in analyzing the results of surveys of existing conditions and in estimating the probable reaction of a given receiving water to the pollutional loads that are to be imposed upon it.

The present series of papers interprets certain experimental investigations that have been carried out in the authors' laboratories over a long period of years or that are reported in the literature. Mathematical formulation of experimental results has been resorted to, wherever possible, as offering the most concise generalization of laboratory findings and the broadest scope for applying existing knowledge to field conditions. While the inadequacies of the work so far done are fully appreciated, it is hoped that the material included in these studies will enable engineers to estimate, better than heretofore, the effects of decomposing sludge deposits upon the quality of the waters that overlie them. The solution of actual problems, however, may require the arithmetic summation of cumulative effects in place of mathematical integration.

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Appendix to Part VII

Least Squares Fitting of the Autocatalytic Unimolecular Equation.—The least squares analyses of the authors' experimental results were considerably simplified by the fact that values of G_s were small in comparison with values of G_a (see Table XX). This circumstance made possible the substitution of G in place of G_t as an initial trial value. To a high degree of approximation the data could be represented by the equation

$$\frac{dG}{dt} = G' = k_a G_t(G_u - G_t). \qquad (\alpha)$$

In this equation G' and G_t represent the experimentally determined quantities, the latter being directly observed and the former obtained from equation (C) of the Appendix to Part II of these papers. The parameters k_a and G_u are then calculated from the normal equations that follow from the usual least squares procedure of making the sum of the squares of the residuals, $R = kG_uG_t - kG_t^2 - G'$, a minimum. These normal equations may be written as follows:

$$k_aG_u\sum G_t^2 - k_a\sum G_t^3 - \sum G'G_t = 0, \qquad (\beta)$$

$$k_aG_u\sum G_t^3 - k_a\sum G_t^4 - \sum G'G_t^2 = 0. \qquad (\gamma)$$

Equations (β) and (γ) may be solved simultaneously for k_a and G_u.

Next G_s is determined from the relation

$$G_t = \frac{G_uG_s}{G_s + G_ue^{-k_aG_ut}}, \qquad (\delta)$$

which follows from equation (8) making use of the circumstance that G_s is small. In accordance with the least squares procedure G_s may be

* References 1 to 12 are appended to Sections I to III of this series of papers; references 13 to 21 to Sections IV and V.

evaluated from equation (δ) by means of the following normal equation obtained by a method analogous to that used in deriving equations (β) and (γ):

$$G_s = \frac{G_u \sum G_t (G_u - G_t) e^{-k_a G_u t}}{\sum (G_u - G_t)^2}. \qquad (\epsilon)$$

The parameters (G_u, k_a and G_s) determined in this manner provide the necessary information needed for plotting the curves of Figs. 19 and 20. These curves could not be distinguished by eye from curves based upon parameters obtained from a more exact but considerably more laborious least squares method in which the assumption that G_s is small was not made. This would indicate that for practical purposes the autocatalytic equation may be analyzed by equations (β), (γ) and (ϵ) in the event that G_s is less than five per cent of G_a, or G_u.

THE OPERATOR'S CORNER

Conducted by W. H. WISELY, Executive Secretary*
Federation of Sewage Works Associations
Box 18 · · Urbana, Illinois

YOUR MONEY'S WORTH?

Dues paying time is upon us again. When the annual renewal reminder from the Federation's Member Association Secretaries arrives this year, there may be a question in the minds of some worthy members as to the value derived from membership and SEWAGE WORKS JOURNAL in the light of the increased dues required to establish the Federation on a sound, independent and self-supporting financial basis.

Before you do anything rash, just pause for a moment for a bit of calm recapitulation.

Your local Sewage Works Association gives you the contact with other individuals of similar interests in your own region and the opportunity to exchange ideas concerning problems common to that region. It affords a medium for the solution of problems pertaining to welfare of personnel. It yields fellowship and enlarges your circle of friends.

Your Federation expands the above functions of the local Association to an international scope. The reorganization accomplished early in 1941 has paved the way for an almost unlimited horizon of endeavor along new lines. Among the activities approved by the Board of Control in a recent meeting are: recognition of individual achievements in the field; development and promotion of a broad program of public relations; establishment of minimum qualifications for works operation personnel; cooperation with National Defense agencies; studies of post-war problems pertinent to the field; coordination of technical activity and research; publication of Manuals of Practice. Naturally, the Federation does not now have resources to carry out completely all of these functions immediately, but they will be undertaken as available funds and personnel permit.

The dividends derived from either the local Association or Federation are proportional to the participation in their functions. The truly "Active" member reaps much more harvest than does the perfunctory one who confines his support to payment of dues alone.

Your SEWAGE WORKS JOURNAL has long ago established its place as the outstanding technical reference of the sewage works field. It is the medium for the perpetuation of research which has been the foundation of the tremendous progress made in the field in the past 15 years. An

* *Also Engineer-Manager, Urbana and Champaign Sanitary District.*

earnest effort is now being made to develop a portion of the Journal to meet the demand for practical, useful and interesting material relating to sewage works operation. With the continued assistance of operation personnel, there is no reason why this need cannot be adequately fulfilled.

All information necessary to the individual who wishes to keep pace with the constant advancement in sewage and industrial waste treatment is available in Sewage Works Journal—if he uses it. It is as essential a tool in our occupation as is the hammer or saw to the carpenter.

Your money's worth? What other investment will bring you as much return?

MORE EXPERIENCES IN ODOR CONTROL

Due directly to the efforts of C. C. Agar, Senior Sanitary Engineer, New York State Department of Health, a deluge of contributions to the symposium on odor control published in the September issue, was received immediately following the dead-line for that issue. The quantity and quality of this material is such that we present it here as a supplement to the original article.

The Corner had planned an article on "Experience in Sewer Maintenance" for this issue, but will postpone this topic until January. Contributions of letters outlining your routine practice, unusual problems and methods of procedure in sewer maintenance will be greatly appreciated.

We are indebted to the following for the information offered herein:

C. C. Agar, Senior Sanitary Engineer, New York State Department of Health
G. W. Moore, District Sanitary Engineer, New York State Department of Health
M. M. Cohn, Sanitary Engineer, Schenectady, New York
C. W. Gillespie, Village Engineer, Scotia, New York
V. E. Haemmerlein, Village Engineer, East Aurora, New York
Frank Hall, Sanitary Engineer, Mineola, New York
Frank Klinck, Chief Operator, Lawrence, New York
G. E. Pinkney, Superintendent, Webster, New York
E. J. Smith, Superintendent, Niagara Falls, New York
E. A. Sterns, Superintendent, Wanakah, New York

From the Rochester District

Odor control experience in sewage works located in the Rochester District of the New York State Department of Health is summarized in excellent fashion by District Sanitary Engineer G. W. Moore. Methods of control of odors resulting from drying of inadequately digested sludge and from septic sewage are reported:

It is difficult to discuss this problem personally without the District Office taking credit for actions and procedures which were actually instituted by plant operators themselves, either following or preceding conferences between the plant operator and the District Engineer. Therefore, it must be remembered that, to a large extent, much of any credit due should be given to plant operators of the plants in question. I will, therefore, endeavor to indicate under each of the plants the plant operator to whom credit is due.

In the town of Brighton at the Rich's Dugway Plant, considerable complaint arose among adjoining property owners due to the handling of improperly digested sludge. The cause was definitely lack of sludge digestion capacity, combined with low temperatures of the sewage, brought about by the infiltration of cold rain and melting snow in the spring, preventing digestion. The lack of sludge digestion capacity required removal of sludge only partly digested. Mr. Arnold W. Hale, Superintendent of Sewers for the town, reduced complaints due to odors by applying activated carbon to the poorly digested sludge as it was removed to the open drying beds. The condition has been permanently corrected by additions recently made to the plant by the town, whereby adequate digestion capacity, together with heating of the sludge in separate digesters, permits the handling of only properly digested sludge. The complaints due to odors have entirely stopped.

At the Allen's Creek plant of the town of Brighton, due to low temperatures and lack of digestion capacity, partly digested sludge has to be handled at times. In this plant, Mr. Hale is able to control odors due to the withdrawal of sludge to open drying beds, by the application of activated carbon to the sludge as it is withdrawn. The initial effort to control odors emanating from the sludge drying beds, by heavy doses of chloride of lime, failed to control odors entirely and complaints continued. Application of activated carbon to the sludge in the bed, although giving temporary relief, likewise failed to prevent odors. It appears that the activated carbon is more effective when applied to the sludge as it is withdrawn.

At the village of Webster, complaints arose from residents within 300 to 1,000 feet of the plant due to the septic condition of the settled sewage when applied to the trickling filter. The cause was definitely overlong retention period in the settling compartment of the Imhoff tank, whereby sewage became septic and, upon aeration when spread on the trickling filter, gases of decomposition caused quite serious complaint. Chlorination at the inlet of the Imhoff tank, combined with chlorinated iron, aided in reducing complaints, but chlorine consumption at times became excessive. Even the high doses of chlorine sometimes failed to maintain aerobic conditions in the settling compartment. Odors were successfully controlled by pumping well-oxidized supernatant from the final settling tank back to the inlet of the Imhoff tank. In the initial experiment, the settling compartment cleared up three hours after the return of well oxidized plant effluent and the use of chlorine for odor control returned to normal dosage. Mr. Glenn Pinkney, plant operator, has successfully controlled odors by combination of chlorination and periodic return of plant effluent. The operation of the settling compartment will eventually be normal when sewage flow approximates the design capacity of the Imhoff tank, when no further difficulty is expected.

At Lyons, the original plant of the Imhoff tank and trickling filter type had limited sludge digestion capacity and quite limited sludge drying area. For a number of years prior to the time the village remodeled the plant, considerable odor occurred from the handling of poorly digested sludge and the application of septic settled sewage to the trickling filter. The combination of limited sludge drying area, together with limited sludge digestion capacity, resulted in the settling compartment of the Imhoff tank acting similar to a septic tank, at times, with considerable quantities of sludge and scum in the settling compartment. Handling of the sludge resulted in appreciable odor due to the poor condition of the sludge when removed from the Imhoff tank. Likewise with sludge in the settling compartments, the sewage applied to the trickling filter was septic and gases of decomposition were released. Prechlorination of the settled sewage during the summer months, although aiding, did not prevent odors. The village recently completed additions to the plant whereby the Imhoff tank was converted to a 3-compartment sludge digester, equipped with sludge heating facilities. Following the additions to the plant, odors due to operation have been normal, whereas conditions existing prior to remodeling made it nearly impossible for any real odor control, no matter what method was adopted. Mr. Lloyd Lauster was the plant operator and was succeeded by Mr. George D. Warren just prior to the time when the plant was remodeled.

At the village of Dansville, it is necessary to pump sludge from the septic tank direct to the drying beds. The village endeavored to remove sludge as early in the spring and as late in the fall as practicable, in order to avoid complaints due to odors. The sludge was in poor condition and serious complaints resulted when it was withdrawn, and also when it was removed from the drying beds. Due to the inadequate digestion of the sludge as removed from the septic tank, it failed to dry properly, even after months on the drying bed; consequently, considerable odor resulted when it was removed. In the final cleaning of the tank in 1940, activated carbon was added to the septic sludge as it was being pumped from the septic tank. Reports received from Mr. Carl Kidd, Superintendent of Water & Sewers for the village, indicated that the use of activated carbon did reduce odors, although due to the type of sludge being handled, he could not prevent some odor and some complaint. The village is now correcting the odor problem permanently by remodeling the sewage disposal plant.

In the town of Greece the sewage disposal plant is noted for the lack of odor in and about the plant. It is an activated sludge plant with sludge concentration tanks combined with sludge filters and incineration. The plant receives excellent operation, and Mr. William Denise, plant operator, is continually seeking ways and means of reducing odors originating at the sludge concentration tanks. Due to intermittent operation of the vacuum filters and incinerator, it is necessary to retain the sludge in the concentration tanks for a period of days. This means that the sludge becomes septic and some odors can be noticed in the vicinity of the concentration tanks. The use of lime by Mr. Denise has aided but not prevented odors. No nuisance or complaint is caused by the odors; the high type of plant operation, however, makes the plant operator feel it desirable to prevent or reduce the odors at a plant which normally is free from this problem.

In the village of Brockport in 1936 and 1937 considerable plant odor occurred because of the necessity of withdrawing improperly digested sludge from the digestion compartment of the Imhoff tank, when foaming occurred in the early summer. The cause of the foaming was apparently explosive digestion occurring in sewage solids accumulated during the winter months. When foaming occurred, Mr. William Glynn, plant operator, had no other alternative than to withdraw sludge, and, as indicated above, the sludge was only partly digested and odors resulted. Mr. Glynn, on his own initiative, devised methods of handling sludge on open drying beds during the winter months so that when spring arrived the accumulation of sludge in the digestion compartment is limited. During the winter months, sludge was withdrawn to the drying beds to a depth of about 4 inches on clear, cold days. This sludge was permitted to freeze, was removed within 24 to 48 hours in slabs, and disposed of directly by dumping. During the summer of 1938, 1939 and 1940 Mr. Glynn was successful in preventing the annual recurrence of foaming, simply through reducing the volume of sludge accumulation during the winter months when digestion did not progress normally, due to the low temperature. Serious foaming recurred in 1941, but this foaming was due to the addition of industrial wastes and not through excessive accumulation of sludge.

At the village of Fairport, Mr. Arthur Cary, Superintendent of Sewers, was successful in controlling odors which caused some complaint due to the necessity of handling partly digested sludge during the late spring and summer months. The cause was an unheated sludge digestion tank which did not reach normal digestion temperature until late August or September, when it again started to cool within a few weeks. This meant that at this plant, which received careful supervision, sludge had to be withdrawn to the open drying beds during the normal drying season. The application of activated carbon to the sludge when withdrawn permitted the sludge to be dried without undue complaint from odors. The village has corrected this plant operating difficulty, whereby heat from the village incinerator, recently constructed adjacent to the sewage treatment plant, is utilized for heating the digester. Heating of the digester has given permanent correction to the odor problem brought about by sludge, and now properly digested sludge is withdrawn to the drying beds.

Controlling Odors at Pumping Stations.—At Lawrence, New York, Chief Operator Frank Klinck must exercise care to prevent odors at a pumping station located in a residential district, as well as at the sewage treatment works. Recognizing the fact that grease is an important source of odors, Klinck has such accumulations skimmed from the sewage surface and scraped from the walls in the wet well three times weekly. Screenings and skimmings removed here are stored in cans which are removed regularly by the municipal garbage collection service. Septic sludge accumulations in the wet well are swept into the pump suction sump after the grease is removed. This latter measure, with chlorination of the sewage at a dosage of about 2 p.p.m., aids in reducing hydrogen sulfide formation during flow from the pumping station to the treatment works.

At the plant, the bar screens are cleaned six times daily, thus maintaining free flow through the outfall sewer and grit chambers. The settling channels of the Imhoff tanks are skimmed daily and plant effluent is used to hose down gas vent scum and to keep the tank walls and decks clean. The daily hosing of gas vents has served to control fly breeding most effectively.

Activated sludge plants are not often a serious source of odor, but septicity developing during a 7-hour time of sewage flow to the plant at Mineola, New York, resulted in serious complaints until control was effected. Residences are on two sides of the plant, the closest being only 150 feet from the sand filters used to "polish" the activated sludge plant effluent. Frank Hall, Engineer in Charge of Sanitation at Mineola, reports that this condition was brought entirely under control by prechlorination of the raw sewage at a pumping station located a mile above the plant and by admission to the sewers of approximately 100,000 gallons daily of cooling water from a refrigeration plant. The dilution thus afforded represents about 10 per cent of the design flow of the plant.

Formerly, putrid odors were also created at the air lifts employed to pump the return activated sludge. This situation was corrected by disregarding the usual practice of returning activated sludge at the rate of 20 to 30 per cent of the sewage flow and by operating the air lifts at maximum capacity, thus removing the sludge from the final settling tanks in as fresh a condition as possible. In pointing out that this elimination of the final tank sludge blanket had no detrimental effect on the highly satisfactory plant effluent, Hall offers the opinion that the operator of the small plant must often deviate from "the book of rules" due to the wide variation in local conditions. He emphasizes the importance of high-pressure hosing of all surfaces above the sewage level, constant removal of floating solids and grease from sewage surfaces and cautions plant designers "to watch out for covered nooks and crannies that can't be reached with the hose." Credit is accorded Operator Deming Cross for the successful control of odors at the Mineola plant.

The plant at Wanakah, New York, is located on the shore of Lake Erie in the midst of a group of more than thirty cottages of which several are only 25 feet from the plant site. The plant is enclosed by a wire fence covered with honeysuckle vines and is surrounded by closely-planted Lombardy poplars to effectively screen the treatment units and thus minimize odor complaints of psychological origin. Superintendent E. A. Stearns gives considerable attention to the maintenance of attractive grounds. Sewage-borne odors are successfully suppressed by chlorination of the raw sewage just above the inlet to the Imhoff tanks, with a dosage sufficient to give a residual of 0.5 p.p.m. in the tank effluent. A mixture of activated carbon and lime (one part carbon to four parts lime) is scattered as a dry mix over the gas vent scum each day and is occasionally hosed into the scum to reduce odors at the vents. This treatment also gives a digested sludge having good drying characteristics. Superintendent Stearns also uses care in handling screenings, which are placed in a specially constructed wire basket as taken from the screen, left to drain on a shelf in the screen house, and removed daily by the garbage collector.

Determination of Chlorine Dosages.—The manner in which odor control chlorine dosages were established by trial and error at Scotia, New York is reported by Village Engineer C. W. Gillespie:

The plant, for primary treatment only, consists of a clarifier and two digesters with sludge disposal by vacuum filter. Location is at the extreme southeast end of the village with the nearest dwelling approximately 300 feet distant. Operation started in December of 1939 and complaints of odors began in the summer months of 1940.

To eliminate this nuisance, a Wallace & Tiernan MSV chlorinator was installed with points of application to the raw sewage or to the plant effluent. So far, only prechlorination is practiced with the point of application being in the raw sewage before entering the plant and approximately 50 feet ahead of entrance.

Scotia's sewage flow during the summer averages approximately 55 gallons per capita per day and is strong domestic. Suspended solids tests averaged for the last three months, 497 p.p.m. in daytime samples of raw sewage, and has been as high as 785 p.p.m. B.O.D. for April, before chlorination, was 442 p.p.m. in the raw sewage.

The rate of chlorination was not based on the demand tests but rather on a "cut and try" system. Figures indicate that dosages were more than adequate on the basis that odor control requires about half the dosage needed for sterilization. At the start, the chlorine was fed at the rate of 70 pounds per day, in order to kill the odor as quickly as possible. The rate was then gradually reduced until complaints were again received; whereupon the rate was raised until odors disappeared, and then again gradually reduced until finally a rate was found which was effective and yet economical. However, there are still certain times when atmospheric conditions are such that the rate has to be raised to prevent odors.

Records show chlorination as follows:

May—Average daily dose of 45.5 pounds..
June—Average daily dose of 44.3 pounds.
July—Average daily dose of 47 pounds.

The average sewage flow for these months was 430,000 g.p.d.

Tests for residual are taken daily and rarely show in the raw sewage. Due to the low flow during the night and the consequent over-dose during that time, a residual can usually be picked up in the clarifier and sometimes at the outlet wier.

Next year a more comprehensive system of feeding chlorine may be worked out, such as varying the rate at different times of the day and for different days. But the fact still remains that on warm, sultry days with no wind, or wind in the direction of the dwellings, chlorine must be fed at a very excessive rate to prevent any trace of odor in or about the plant.

Sewers laid on very flat grades and with faulty joints which admit flowing sand in the wet weather months of high infiltration, are responsible for extreme septicity of the sewage received at the East Aurora, New York treatment works. In hot, dry weather, the low sewer velocities and deposits of septic solids in the sewers permit excessive production of hydrogen sulfide. The problem is not confined to the plant alone, as odors emanating from manholes on hot, humid evenings have caused complaint in some parts of the village. Periodic removal of the sand accumulations which obstruct the sewage flow and cause deposition of solids, flushing with the fire hose, and treatment with chloride of lime have been employed in an effort to control this condition. Opportunity for further hydrogen sulfide production is afforded in the Imhoff tank at the sewage works, which is reported by Village Engineer V. E. Haemmerlein to be "out of balance" in relative volumes available for sedimentation and digestion (sedimentation volume being too large).

Attempts in 1935 to control odors at the plant by chlorination alone were unsuccessful. Later, a Scott-Darcey unit was developed by passing chlorine solution upward through a tower made of 30-inch tile and 9 feet deep filled with scraps from a sheet metal stamping shop. Application of this iron-chlorine solution to the raw sewage just ahead of the Imhoff tank, together with daily applications of a dry mix of activated carbon and lime to the gas vents, sufficed to afford adequate control of odors until 1939, but has not been satisfactory since that time. Conversion of the existing primary treatment works to separate sedimentation and digestion units having more appropriate retention periods is now under way and Engineer Haemmerlein concludes his remarks "hopefully and optimistically" with the following observation:

> If this does not eliminate the odors, we had better try educating the public to eating such foods as will not convert into ill-smelling H_2S and have our chemists invent substitutes which will create synthetic aromas of rose and violet.

The treatment works at Webster, New York comprises a grit chamber located about 0.75 mile above the plant proper (to protect an 8-inch inverted siphon), an Imhoff tank, trickling filter, final tank and sand filters for effluent "polishing." Numerous odor complaints resulted in the first season of operation and an endeavor to effect control by application of a bleaching powder solution to the raw sewage was not successful. Definite improvement resulted following the installation of chlorination equipment and, later, of a scrap iron tower similar to that described above at East Aurora. Superintendent Glenn E. Pinkney then experimented with the return of plant effluent to the raw sewage and found that the effectiveness of the chlorine was improved almost immediately. This recirculation made it possible to carry a chlorine residual at the trickling filters with only half the chlorine dosage originally applied. In consequence, a special recirculation pump of 50 g.p.m. capacity was installed and is operated from 7 A.M. for 12 to 15 hours daily, depending upon the weather. The pump is equipped with automatic time controls to obviate the need for manual attention.

Believe It or Not!—Some of the largest chlorine manufacturing plants in the United States are located at Niagara Falls, New York. The problems of Superintendent Edward J. Smith at Niagara Falls indicate that "the cure can be worse than the disease."

The Niagara Falls Sewage Disposal Plant has gas troubles to the Nth degree, but contrary to the usual installation, the gases are not caused by septic action in the incoming sewage. In fact, surprising as it may seem, there has never been even the faintest sewage odor in the two years of operation!

The gases are entirely of a chemical nature and contributed by large chemical and allied industries. Chlorine gas predominates, either in a pure or combined state with other gases. The four large commercial producers of chlorine gas, as well as industries using chlorine in their manufacturing processes and other general chemical wastes, discharge into the sewers constantly.

To give the reader an idea as to the extent of the gas troubles, it is merely necessary to state that during 50 per cent of the time the sewage contains enough residual chlorine gas to effect complete disinfection, and at such times no chlorine is added during the plant operation. In fact, a chlorine residual of 200 to 300 p.p.m. is a frequent occurrence and a maximum of 800 p.p.m. has been encountered.

These gases are not in stable solution, but are entrained in the sewage. Every rapid or fall, such as weir action, liberates vast quantities of gas. This is continuous throughout the plant and the amount liberated in the discharge outfall seems to be as much as at the entrance to the plant. The action is similar to soda water. Gas is liberated when pouring into a tumbler. Allow a few seconds and the liquid becomes nearly quiescent. Stir vigorously and gases are again liberated. The stirring can be done several times with similar effect until the charge is exhausted. With the many falls and rapids necessary to consume the loss of head of 110 feet going through the plant, like the soda water the sewage is well stirred, the only difference being that the sewage never exhausts the charge.

The gases have various effects. The reader is familiar with the effect of pure chlorine gas, but chlorine when mixed with other gases has the properties of many of the gases used in the last war, tear gas, gases causing nausea, vomiting, etc., when in sufficient concentration, but disagreeable at all times in lesser concentration.

Gas troubles were anticipated and quite an elaborate system of trapping and ventilation worked out in the design. In fact, ventilation of some 120,000 cubic feet of free air per minute was installed, which I believe is a record. However, this amount is only a "drop in the bucket" to that actually necessary. It is estimated that about ten times that amount might probably be required. In turn, increased ventilation would require ten times the heating facilities and prove very expensive.

Remedial work has been constantly done. All openings have been enclosed where possible and many beneficial changes in the ventilation system accomplished. Goggles and gas masks have been furnished operators and have to be frequently used. Operating under such conditions results in greatly decreased efficiency of the personnel and at times only their loyalty keeps the plant running.

Besides personal discomforts, the liberated gases have a very deteriorating effect upon equipment, metals and electric devices. This is specially the case in humid or cold weather when the condensation on metallic surfaces absorbs the gases making weak hydrochloric and other acids, which as can be imagined, are very corrosive on unprotected surfaces. As a remedy for this condition, a full time painter is employed and as fast as he completes one round he is obliged to begin another. A part time electrician is necessary for electrical work. Contacts, insulation, switchboards and automatic devices have to be constantly overhauled.

It is also interesting to note that war activities have increased industrial production to such an extent that the last six months, flows have increased 20 per cent and suspended solids about 10 per cent. With this increase, gas troubles have also increased in the same ratio.

Conclusion

It is hoped that this compilation of experience in odor control practice, begun in the September issue of *This Journal*, may be of some assistance where such problems still exist. Although most of the control measures described are not necessarily new, some interesting combinations of methods to overcome specific local problems have been included.

A pioneer in sewage works odor control, Morris M. Cohen, who serves as Sanitary Engineer for the City of Schenectady, New York, and as Editor of *Sewage Works Engineering*, summarizes current practice briefly, yet completely:

> About a decade ago I coined the expression "The Three C's of Odor Control." The C's are: Care, Cleanliness and Chlorination. In this succinct phrase, I believe, is summed up the secret of nuisance-free plant operation. Each plant can supply its own interpretation of these three factors, yet they remain basically the same for every problem, regardless of the nature of the sewage treated, the type of plant, the location of the plant and the personnel of operation.

Fig. 1.—Rich's Dugway Plant at Brighton, New York. Note proximity of residences.

> *Care* in operation will prevent many odors which might take a pound of cure to correct. Interwoven with this fundamental of odor control is efficient operation of treatment units. Proper sewer servicing, intelligent care of grit chambers, screens, tanks, digesters, and like facilities will prevent the production of odors. Septicity can be prevented in many cases and the reward of care is carefree service.
>
> *Cleanliness* in operation is an inviolable rule. The clean plant is normally clean-smelling. The presence of debris around plant units is offensive to the eye—and what offends the eye offends the nose. There is little excuse for improper disposal of screenings, skimmings, sludge and other odor-producing materials which arrive at the plant in unending stream. Cleanliness means plant upkeep. The plants with nice lawns, trim roadways, intelligently laid-out flower beds and clean buildings are builders of favorable public opinion. They seldom are the whipping boys of neighborhood complaints. Cleanliness extends to the plant personnel. Unkempt workmen mean unkempt workmanship. Dress up the men and you achieve safety and a pride in the job, both of which result in a cleaner plant and a fresher plant. The fellow who spits in the corner of the power house or pump room may cuss about "sissy stuff" when he is told that such slovenly

methods do not go, but he will soon perk up and see filth and odor-producing materials which he never saw before.

Chlorination is the outstanding odor destroyer in the sewage treatment field. The intelligent use of chlorine will prevent the septicity of sewage, or correct such conditions when they exist. Prechlorination of sewage will result in improved conditions around screen and grit chambers, settling tanks, etc. The agitation of sewage in treatment devices, flowing over weirs, passing into dosing tanks, being distributed over trickling filters and even flowing in channels is a definite source of odor dissemination. The use of chlorine will prevent these points from becoming foci of objectionable conditions.

The best advice I can give the operator is—" Practice the Three C's of Odor Control." Your plant will benefit, and the neighbors will bless you.

BARK FROM THE DAILY LOG

By John C. Mackin

Guest Contributor

Superintendent of Operation, Metropolitan Sewerage District, Madison, Wisconsin

November 1—Emptied Aeration Tank No. 1 for inspection and maintenance and found everything in fairly good shape. Began preparation for painting the expansion joints, inlet gates, air piping and effluent weirs with two coats of paint. The oxygen content of the mixed liquor is O.K. for activated sludge but adds to metal corrosion problems at aeration tanks.

November 3—Took microscopic inventory of the activated sludge and found considerable heavy, stalked growth, some fine filaments, many active Vorticella and small hypotrichs, and the usual numbers of Epistylis, rotifers and Arcella. Sludge settling well.

Had a visitor of note today when our 3-year old daughter "Dixie" dropped in for a call, after taking "French leave" from home. Discipline her? How could I!

November 5—Broken link on drive chain of No. 3 Primary requires replacement.

November 6—Unloaded 15 tons of chlorine. **Note: It will be evident that this diary represents some year "B. P." (Before Priorities)!**

November 7—Meeting of Commissioners and industrial officials to discuss some of our industrial waste problems. Getting both points of view on matters like this certainly helps to work out such problems!

November 9—Now that No. 1 Aeration unit is back in service, we are draining No. 2 Primary for inspection, painting and repairs.

University students out to take samples for laboratory study. Two gallons less to treat to-day.

November 11—King Winter came breezing in to-day on a high wind. Temperature dropped about 45 degrees. Br-r-r!

November 12—Temperature 9 degrees above this morning! Ice cracked valves at gas purifiers and also forming between covers and walls of sludge digestion tank. Ordered out some hay for insulation and provided heat at the purifiers to prevent further damage.

The drop in sewage temperature resulted in a 3.3 p.p.m. dissolved oxygen content in the aeration tanks—somewhat higher than usual.

November 13—Continued cold—6 above this morning. Strong shot of phenol waste greatly increased the potency of the raw sewage. Resulted in a marked gas odor at Booster Station No. 2, a heavy accumulation of oil and tar at the primaries and interference with the activated sludge settleability.

November 15—Weather moderated sufficiently to permit class of nurses from St. Mary's Hospital to come out for lecture and tour of inspection.

November 16—Applying chlorine to mixed liquor in effort to remedy tendency toward bulking of activated sludge.

This afternoon—Wisconsin 27, Indiana 10! A brief pause at this juncture for celebration!

November 18—High ammonia (30 p.p.m.) noted in yesterday's raw sewage composite. Examination of the bulking sludge shows many large colonies of Epistylis and Carchesium, many Gastronauta and other hypotrichs, many amoeba and very few rotifers.

As part of the repairs to Primary Tank No. 2, we are grinding down the wearing shoes on the flights and smoothing out the "washboard" ridges at the effluent end of the guide rail on which the shoes ride. We expect this work to prevent jerky operation of the mechanism which has bent the flights and roughened the guide rail. Sent the bent flights to the foundry for straightening.

November 25—Activated sludge settling very well again.

Visited industrial plant to-day and conferred regarding technique of B.O.D. determination. This industry intends to make routine analysis of its own wastes.

Began draining Final Tank No. 3 for inspection, painting and repairs. Found that replacement of the drag chain will be necessary (Towbro mechanism).

November 27—If it isn't one thing, it's another! Now the Imhoff tanks are entering a foaming stage. We began removing scum from the vents, liming and circulating the sludge.

December 1—Having trouble at the gas dome on Digester No. 3, where the seal is blowing repeatedly. Traced trouble to gas meter serving this unit and repairs to the meter cleared the difficulty.

December 3—Dr. Sarles brought out his Bacteriology Class from the U. of Wisconsin for an inspection tour. Strange that the bus driver is always in a hurry for us to get through. Could the co-ed element have something to do with it?

December 6—Another broken drive chain link on Primary No. 4. Replaced link after lowering water level a little. This link breakage is getting to be a joke that "ain't funny, Magee," and we are going to take up with the manufacturer the possibility of replacing these chains with heavier ones such as those in use at Primaries No. 1 and No. 2.

December 11—Received a batch of counterfeit money in the screenings at one of the pumping stations. Well, that's one way of "passing the queer," as the detective stories put it!

December 13—Removed Gas Purifier No. 2 from service for recharging and placed No. 1 in operation. The iron sponge from No. 2 is black throughout with iron sulfide, and we soaked the pile several time during the day to avoid burning. We are very careful in handling the used sponge because iron sulfide oxidizes readily in the presence of air and often generates sufficient heat to ignite.

December 16—The gas engine cooling system is requiring 90 gallons per day of make-up water. Too much!

University of Wisconsin orders 15 tons of our sludge by-product "Nitrohumus" for use on its athletic fields. Could this be the reason that we have the best football field in the Big Ten—or is it Nine? (Notice that we didn't say "best team," but we're hopeful of next year, as usual.)

December 19—Service man here to adjust our return sludge meter. Welders repairing rollers of cover on Digester No. 2.

Another conference to-day in connection with the industrial waste. These take a lot of time but are worth it!

December 22—Activated sludge not settling well so began chlorinating return sludge again. Examination of sludge reveals some fine filaments, rotifers, a few Lionotus types and some Vorticella—generally a rather inactive sludge.

Found the leak in the water circulation line at a manhole near the Blower Building. Tightening of joints effects a reduction in make-up water to 10 gallons per day.

December 26—Santa Claus should have brought us a new grit chamber mechanism. The chain links and connecting pins are considerably worn so we removed one link from each chain to take up the slack until permanent repairs can be made.

We have been long seeking a "ghost" to haunt the filamentous growths in the activated sludge out of existence and at last we think we've found several. Our Xmas neckties!

December 27—Activated sludge is rather finely dispersed—a condition which is not unusual here in winter months of low sewage temperature.

Difficulty in starting gas engine found caused by a faulty magneto, which was overhauled.

December 30—Gas vents of Imhoff No. 1 foaming vigorously. Well, it's an appropriate way to start the New Year, at that, since the entire country will be seeing a lot of foam during the next 48 hours!

INTERESTING EXTRACTS FROM OPERATION REPORTS

Mansfield, Ohio (1940)

By J. R. Turner, *Superintendent*

Summary of Operation Data

Item	1940 Average	
Tributary population (estimated)	42,000	
Sewage flow (average daily)	3.32	m.g.d.
Per capita	79	g.p.d.
5-Day B.O.D.:		
Raw sewage	237	p.p.m.
Primary effluent	156	p.p.m.
Removal—primary treatment	38%	
Final effluent	15	p.p.m.
Removal—complete treatment	94%	
Suspended solids:		
Raw sewage	200	p.p.m.
Primary effluent	91	p.p.m.
Removal—primary treatment	54%	
Final effluent	13	p.p.m.
Removal—complete treatment	93%	
Sludge digestion:		
Raw sludge quantity per m.g. sewage *	6,220	gallons
Solids content	4.17%	
Volatile content	74%	
Gas production (daily)	60,600	cu. ft.
Per capita daily	1.43	cu. ft.
Per lb. vol. solids added	11.6	cu. ft.
Digested sludge—solids content	2.3%	
Volatile content	57%	
Activated sludge:		
Mixed liquor—suspended solids	1,085	p.p.m.
Settleable solids (30 min.)	29%	
Sludge index	272	
Return sludge	21%	
Suspended solids	4,050	p.p.m.
Aeration period	7.1	hrs.
Applied air—per gallon sewage	0.52	cu. ft.
Per lb. 5-day B.O.D. removed	437	cu. ft.
Operation costs:		
Per million gallon treated	$20.35	
Per capita connected per year	$ 0.59	

* Mixture of primary sludge and waste activated sludge.

Aurora, Illinois (1940)

By Walter A. Sperry, *Superintendent*

For Benefit of Visitors.—The outstanding accomplishment of the year in the way of an addition was the planning and installation of a flow sheet completely describing the sewage treatment process by pictures, notes, Imhoff Cones and bottled samples. Every effort was made to keep the description sufficiently simple so that anyone could follow and understand it. This permanent board, placed near the main entrance, was supplemented by printed descriptions, in bold type, placed appropriately in each of the several divisions of the plant.

Preparation for Repainting Old Floors.—During the winter and following the installation of the engine-generators the entire floor of the pump room was gone over with a grinding machine to remove the old paint, reduce somewhat the roughness and prepare the way for a much better "knitting in" of the paint coats. This resulted in a better sealing of the surface and a lesser tendency of the paint to come off due to moisture from beneath.

Slag Insulation Prevents Condensation.—Abandoned the use of ground cork as an insulating covering to the 1,000 gallon plant water supply tank and completely re-covered the tank and pipe system with a heavy slag insulating material, to a depth of about two inches. While this work cost nearly two hundred dollars, it removed one of the most annoying problems in the plant since ground cork failed as an insulating medium due to a temperature differential in the summer time of approximately 50 degrees F. which resulted in a constant quantity of water on the floors.

Painting of Primary Clarifier Mechanisms.—The problem of finding a paint for the underwater mechanism of the clarifiers continues to be unsolved. Early in 1940 Clarifiers 1 and 2 were painted with a material under trade name of "Rustex," followed with a coat of special rubber-base paint, which was practically soluble rubber. This clarifier remained in operation for about one year, but on dewatering the results were completely disappointing since there was no vestige left of rubber or the prime coat of "Rustex."

Due to the grease content of raw sewage and lack of oxygen it is questionable whether the underwater structures of the clarifiers would ever be much damaged while in use. The major damage is in the idle periods when the clarifiers stand empty. It is questionable, therefore, whether time and effort spent on painting is not a total loss since the complication of the structure makes it impossible to clean sufficiently all portions of the structure to raw metal. This appears to be the only condition under which there is any hope of paint adhering; and then only under the condition of using highly specialized paints as recommended generally by the Aluminum Company of America, where bakelite base varnishes with chromium salts as an inhibitor are followed by aluminum pigment paints.

Alum as Sludge Drying Aid.—During the year 16,600 pounds of alum were used for dewatering sludge, during the winter, spring and fall months. Alum is not used in the summer time due to the enlarged bed area and the more consistent drying weather. An extensive laboratory study of the characteristics of alum, as compared with other dewatering agents in use, such as iron salts and activated carbon, was made and these results proved so interesting that it has been written up, in detail, in the SEWAGE WORKS JOURNAL for September, 1941. While alum has been used for this purpose since early in the 1920's, not much discussion was found in the literature so that the details of this work may be a useful contribution to the general literature of sewage treatment.

Final Settling Tank Problems.—Two annoying operating details of the secondary basin occurred during the year.

One was of the nature of a "Let that be a lesson to you," as Andy says. During the filter unloading period in March and April it was

Summary of Operation Data

Item	1940 Average
Tributary population	49,000
Sewage flow (daily)	6.75 m.g.d.
Per capita	138 g.p.d.
Screenings removal	1.48 c.f. per m.g.
Grit removal	3.20 c.f. per m.g.
Volatile content	42.8%
5-Day B.O.D.:	
Raw sewage	150 p.p.m.
Primary effluent	94 p.p.m.
Removal—primary treatment	37.4%
Filter effluent	24 p.p.m.
Final effluent	16 p.p.m.
Removal—complete treatment	89.3%
Suspended solids:	
Raw sewage	189 p.p.m.
Primary effluent	78 p.p.m.
Removal—primary treatment	58.7 %
Filter effluent	64 p.p.m.
Final effluent	32 p.p.m.
Removal—complete treatment	83.1%
Sludge Digestion:	
Raw sludge quantity per m.g. sewage *	2,830 gal.
Solids content (primary sludge)	4.7%
Volatile content (primary sludge)	71.3%
Transfer sludge to second stage:	
Solids content	2.2%
Volatile content	54.3%
Gas production (daily)	55,170 cu. ft.
Per m.g. sewage	8,180 cu. ft.
Per capita daily	1.13 cu. ft.
Per lb. volatile solids added	11.03 cu. ft.
Operation costs:	
Per m.g. treated	$9.64
Per capita per year	$0.49

* Primary sludge plus filter humus.

not appreciated how much material was being discharged into the secondary basin. While the volume of solids removed increased somewhat, it was not enough to arouse suspicion until the shear pins in the drive began to break more frequently than usual. On investigation, with the periscope, we found, to our amazement, three to four feet accumulation in the tank. As a result of this the filter effluent was discharged direct to the river from April 4–23, taking advantage of higher flow than usual while the tank was being emptied. The obvious lesson of this experience was the more frequent and periodic use of the periscope.

The second difficulty was the failure of three of the gears in the chain transmission system, probably due to overloading. This was later found to be due to high concrete on the floor of the west side. These gears failed November 11, and it was not possible to get replacements until February 25, 1941. This was a reflection of the present defense program situation. As a result of this experience, a duplicate set of gears was immediately ordered as a stand-by set.

Worcester, Massachusetts (1940)

By John H. Brooks, Jr., *Superintendent of Sewers*

Plant Undergoes Shake-up.—The most interesting meteorological facts were the occurrence of two slight earthquakes or disturbances; the first, about 2:20 A.M., December 20, was of short duration and more noticeable than the second, which occurred about 8:45 A.M., December 24.

Cost of Handling Grit.—Each grit chamber was flushed and cleaned eight times during the year. A total of 993.4 cubic yards of material were removed from 7967.1 million gallons of sewage, an average of 3.35 cubic feet per million gallons. The cost of cleaning the chambers was $381.89, an average of 38.4 cents per cubic yard of material removed.

The sand filter on to which these flushings are discharged was cleaned, September 11–17; 717 cubic yards of material were removed, using the Barber-Greene loader, at a cost of $440.89, an average of 61.5 cents per cubic yard. In November, the over-head loader from the Bureau of Streets, used for removal of dried sludge from the winter area, removed one flushing, 113 cubic yards, for $36.24, an average of 32.1 cents per cubic yard. The total figures were 830 cubic yards, costing $477.13, an average of 57.5 cents per cubic yard.

The cost of cleaning the filter was cut using the over-head loader and the larger trucks. The Barber-Greene loader worked 32.2 hours to remove 717 cubic yards, while the over-head loader worked 3 hours to remove 113 cubic yards. Three ground men are necessary to move the grit so that the Barber-Greene will load it, while only one man was used with the new loader. Available trucking slightly favored the latter machine.

Trickling Filter Observations.—Less nozzle cleaning was done than in any year since the filters were placed in operation. The usual filter flooding for fly control was practiced from May to September and because of warm, pleasant weather in October, it became necessary to again flood each section of filter. A second warm spell quickly changed to colder temperature and it was not necessary to resume flooding a second time.

Unloading of clogging material from the filters occurred in May and June and a small amount in July. The Fall unloading occurred to a lesser extent in October and November. The October unloading appeared a bit unusual inasmuch as the colder weather had not set in to any appreciable extent. The results indicate that the unloading was not nearly so extensive as in 1939. This is not surprising, since the 1939 unloading was heavy over an unusually long period of time.

The laboratory data indicate that the greater content of organic matter in the filter influent affected that of the effluent. In spite of slightly greater organic content, the average filter effluent of 1940 was of practically the same average stability as that of the previous year. This is accounted for by the considerable increase of nitrate nitrogen and dissolved oxygen contained in the filter effluent of 1940.

Undigested Secondary Sludge to Drying Beds.—The average detention period of the trickling filter effluent in the secondary or final settling tank was 2.0 hours. Sludge was pumped from the tanks once each week during the winter season to the winter sludge bed area. During the summer, sludge was pumped to the concentration tanks on Monday; top water drawn off the following morning; tanks refilled with sludge each morning through Thursday and on Friday, the concentrated sludge was pumped to the small drying beds. During the unloading of the filters it was necessary to pump a large quantity of sludge to the winter bed area. The secondary tank weirs were cleaned once each week.

Comparison of Sludge Bed Cleaning Costs.—The general layout for sludge disposal will bear repeating. The sludge drying bed area is in three parts, all of which are laid out on sand filters formerly used for intermittent filtration of sewage. No special drainage system or shallow beds have been provided. The old drainage system consists of six inch tile pipe, laid with open joints, in lines thirty feet apart. The summer Imhoff tank sludge is dried on 21 one-quarter acre beds; summer secondary tank sludge, after concentration, is dried on 32 18×110 feet beds and during the winter, both sludges (the secondary without concentration), are pumped to 42 old one-acre beds. The distribution system from the force main is gravity flow in the large pipes formerly used for sewage.

The inlets to the one-acre beds are located on the side of these pipes some distance above the invert which results after each winter's use in a residual deposit of sludge which must be removed. These inlets should be removed, the lateral distributor pipe broken out to the invert and 10 or 12-inch pipe laid connecting the distributor pipe to the bed.

Removal of dried sludge from the beds, using welfare help, was started May 6. Available welfare help was insufficient to provide more than one truck loading crew and seven temporary men were employed, July 15. The number of temporary laborers was increased to 12 on September 5 and further increased to 17 on October 2. One truck crew was transferred October 22 and the other two, November 20.

From October 10 to November 13, an overhead loader or excavator, together with a number of 2 cubic yard Federal trucks (short wheel base necessary) were rented from the Bureau of Streets. It was necessary to clean around the edges and to level the beds with the shoveling gangs.

The total cubic yardage of dried sludge removed from the beds in 1940 was 21,438.5 of which, 10,667.8 cubic yards were removed previous to and independent of the work done by the excavator. The excavator removed 9,075.7 cubic yards and 1,695 cubic yards were removed during the clean up following the excavator, a total of 10,770.7 cubic yards. Approximately one-half of the dried sludge was removed by the excavator and the clean-up crews; this work being done in five weeks time.

The summary of costs of sludge removal is as follows:

Welfare	Cubic Yards	Cost *	Cost per Cubic Yard
Shovel and fork, Imhoff and winter sludge	3,788.5	$ 2,578.00	$.680
Barber-Greene Loader—winter sludge	1,426.3	660.72	.463
Secondary sludge	418.5	316.68	.757
Temporary			
Shovel and fork, Imhoff and winter sludge	5,034.5	3,543.24	.704
Excavator			
Excavator	9,075.7	2,598.05	.286
Clean-up	1,695.0	1,476.09	.871
Totals	21,438.5	$11,172.78	$.521

* No foreman charge.

All labor at 50 cents per hour, except operators of Barber-Greene Loader and the Excavator. Welfare free labor, rated at 50 cents per hour, $2207.74, Trucks, $1.25 per hour. Trucking comprised approximately one-third and labor about two-thirds of the total cost.

No attempt was made to clean 9 one-acre beds on which sludge had been pumped a few years ago. Driveways must be constructed which are suitable for use by the Excavator and the larger trucks. Two one-acre beds which have been used each winter could not be cleaned owing to the wet conditions of the bottom portion of the sludge.

It is obvious that the cost of removal of dried sludge depends upon the method used. The availability of welfare labor is very uncertain. The 9 beds which were not cleaned will involve an additional 4500 cubic yards of dried sludge and the clean-up will account for an additional 900 cubic yards of sludge. The annual total yardage of dried sludge to be removed from the beds will amount to from 25,000 to 27,000 cubic yards.

Approximately 8,000 cubic yards of sludge will be removed from the summer beds and should be removed by labor using forks and shovels. This is necessary in order to avoid mixing sand and sludge. The cost of removal of this sludge will approximate 65 to 70 cents per cubic yard. The remainder of the sludge, 17,000 to 19,000 cubic yards, will be removed from the winter beds and can be done for approximately 30 cents per cubic yard.

Owing to the late season of cleaning the winter beds, 4 clean beds can not be used until we are able to clear the pipe-line of old sludge. All other pipe lines were cleaned, providing 27 one-acre beds for use during the coming Winter and Spring.

Summary of Operation Data

Item	1940 Average
Population served	191,000
Sewage flow (average daily)	21.77 m.g.d.
Grit removal	3.35 cu. ft. per m.g.
Screenings removal	1.82 cu. ft. per m.g.
Imhoff tanks:	
Detention period	2.7 hours
Per cent removals:	
5-Day B.O.D.	38.0%
Suspended solids	64.2%
Settleable solids	91.0%
Digested sludge:	
Specific gravity	1.031
Solids content	6.94%
Volatile content	43.9%
pH	6.8
Trickling filters:	
Sewage quantity applied (per acre daily)	1.55 m.g.
Nozzles cleaned (per acre daily)	10.0
Secondary settling tanks—detention period	2.0 hours
Analyses:	
Suspended solids:	
Raw sewage	226 p.p.m.
Imhoff tank effluent	81 p.p.m.
Trickling filter effluent	119 p.p.m.
Secondary tank effluent	67 p.p.m.
5-Day B.O.D.:	
Raw sewage	192 p.p.m.
Imhoff tank effluent	119 p.p.m.
Trickling filter effluent	27 p.p.m.
Secondary tank effluent	21 p.p.m.
Nitrates plus nitrites (plant effluent)	5.58 p.p.m.
Dissolved oxygen (plant effluent)	4.96 p.p.m.
Relative stability (plant effluent)	90%
Operation costs:	
Per million gallons treated	$6.55
Per capita served per year	$0.27

BOTTLE EXPERIMENTS AS GUIDE IN OPERATION OF DIGESTERS RECEIVING COPPER–SLUDGE MIXTURES

By H. T. Rudgal, *Superintendent, Sewage Treatment Plant, Kenosha, Wisconsin*

Among the industrial wastes received for treatment at the Kenosha, Wisconsin sewage treatment works are copper pickling wastes and rinse waters which seriously interfere with sludge digestion. Certain other industrial wastes, however, have had beneficial effects due to precipitation in sedimentation units which has made possible suspended matter removals averaging over 70 per cent.

The high copper content of the raw sludge resulted in concentrations of approximately 3000 p.p.m. in the bottom layers of the digester and the process was seriously impaired. In an effort to determine the limiting concentrations of copper which would inhibit digestion, two experiments were undertaken in which digestion was observed while treating sewage sludge in the presence of known amounts of copper.

Digestion Experiment No. 1

(Sewage Sludge Plus Copper)

Duration of test—58 days.

Apparatus:

Five 10-Liter wide-mouth glass bottle digesters plus appurtenances for measuring gas production by water displacement.

Purpose of Experiment:

To determine toxicity of copper on sludge digestion, when mixed with sewage sludge. To determine copper concentration required to stop digestion action completely.

Method:

Each of five bottle digesters received 4000 gms. of raw (no seed) sludge, of which 53.3 per cent was volatile matter. Bottle " A " was the control and received no addition of copper. To bottles " B," " C," " D," and " E " were added copper charges equal to 150, 250, 300, 350 parts per million of the sludge volume. The contents were thoroughly mixed and the pH adjusted to 7.0 with lime. The bottles were then sealed except for the gas outlets and no further additions of sludge or copper were made during the duration of the test. Room temperature was maintained at 80 to 85 deg. F.

Data:

Bottle No.	P.P.M. Copper in Sludge	Total c.c. of Gas Produced (58 days or less)	
"A"	0	38300	
"B"	150	25850	
"C"	250	190	Little activity throughout duration of test.
"D"	300	150	
"E"	350	180	

Conclusions:

The conclusions to be derived from this experiment are that a copper concentration between the limits of 150 and 250 parts per million of the digester sludge is a toxic dose capable of seriously affecting the sludge digestion process and practically stopping all sludge bacterial action. Also sewage sludges with smaller concentrations of copper are affected to an extent that digestion action is not as complete and gas production proportionally less.

Digestion Experiment No. 2

(*Daily Additions of Sewage Sludge plus Copper*)

Duration of test—30 days.

Apparatus:

Three 10-liter wide-mouth glass bottle digestions plus appurtenances for measuring gas production by water displacement.

Purpose of Experiment:

To determine the effect on digestion and gas production of daily additions of increments of sewage sludge plus copper.

Method:

Each of three bottle digesters was placed into operation with 4325 gms. of a mixture of copper free raw and seed sludge, of which 47 per cent was volatile matter. The sludge volume in these bottle digesters was proportional to the amount of sludge in the regular plant digester tanks. All bottles received daily sludge charges proportional to the amount of sludge pumped daily to the plant digesters, except that copper was added to Bottles " B " and " C " in an amount equal to 50 and 100 parts per million respectively, of the sludge additions. Bottle " A " was the control and received daily additions of copper free sludge only. Room temperature was maintained at 80 to 85 deg. F.

Data:

Table Showing Gas Production on Specific Days

Bottle	"A"	"B"	"C"
Duration of Test in Days	(Control) Daily Additions of Sludge. No Copper	Daily Additions of Sludge plus 50 P.P.M. Copper	Daily Additions of Sludge plus 100 P.P.M. Copper
	c.c. Gas Produced	c.c. Gas Produced	c.c. Gas Produced
6th day	2,500	2,400	2,650
8th day	2,850	2,500	2,200
10th day	2,800	2,700	1,000
12th day	2,820	2,200	1,000
15th day	2,175	1,600	325
18th day	2,150	960	75
20th day	1,950	520	0 = No digestion
24th day	1,620	250	0
27th day	1,475	100	0
30th day	1,450 Still active	0 = No digestion	0
Total gas produced during experiment	60,900 c.c. per 30 days (still active)	37,400 c.c. per 30 days (inactive)	23,200 c.c. per 21 days (inactive)

From this experiment it was determined that at the time digestion and gas production showed a drop below that of the control, copper free digester, that sludge in digesters "B" and "C" had copper concentrations of only 85 and 93 parts per million respectively. From that time on both "B" and "C" digesters slowed up in activity and gas production.

Digester "A"—Digestion and gas production was still active and in progress at the end of the 30 day period.

Digester "B"—Digestion stopped at the end of 30 days. The copper concentration of the digester sludge was determined to be 230 parts per million at the end of the digestion period.

Digester "C"—Digestion stopped at the end of 21 days and the copper concentration of this sludge was found to be 195 parts per million.

Conclusions:

From this experiment it can be concluded that daily additions to the digesters of raw sludge containing only 50 to 100 parts per million copper, would eventually accumulate to become a toxic dose of enough concentration to stop digestion action completely, at Kenosha, at a time when the copper content of the entire digester reached approximately 200 parts per million of copper.

Also, since the ratio of sewage flow to sludge pumped to the digester was in the ratio of 515 to 1, during the time the copper wastes were included in the flow through the treatment plant, it is apparent that what may be termed small amounts of copper in parts per million of the sewage flow, will become concentrated into toxic copper doses in the sludge as pumped to the digesters. At Kenosha copper concentrations in the sludge in the digestion tanks were found to be as high as 3000 parts per million in the bottom layers of sludge.

GADGET DEPARTMENT

"Air Lance" for Clearing Incinerator Rabble Arms

Submitted by

Clyde L. Palmer, *Plant Supervisor*
Detroit, Mich.

Clogging of rabble teeth in the drying hearths of Detroit's multiple-hearth incinerators by accumulations of rags has been a troublesome problem and the only solution appeared to be in the development of special equipment to meet the prevailing conditions. The gadget shown in Figure 1 is an "Air Lance" which is used to blow the accumulated rags out of the incinerator rabble teeth.

The lance is simply a ⅜-inch tube about three feet long, fitted with a button type, quick-acting valve for operation on the plant compressed air system. The lance is light and easily manipulated, allowing it to be used with safety on the moving rabble arms and teeth as the assembly revolves past the incinerator doors. Previously, the feed had to be stopped and the mechanism shut down for cleaning, but the lance has made it possible to perform the cleaning operation without interruption of incineration and with much less effort on the part of the operators.

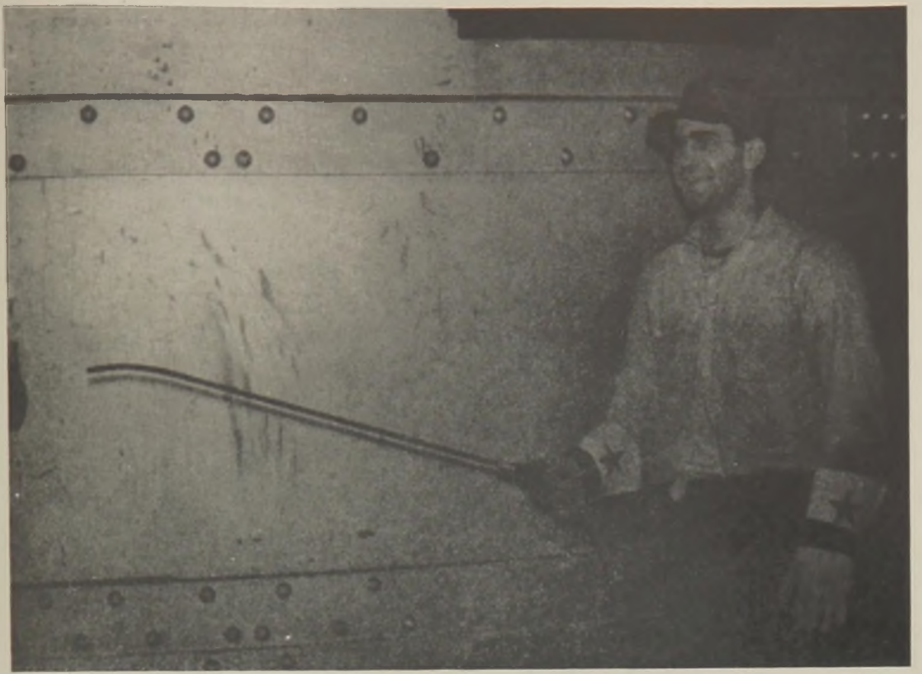

FIG. 1.—"Air Lance" used for cleaning incinerator rabble teeth at Detroit, Michigan. (Clyde L. Palmer, Plant Supervisor.)

A Standard Rain Gauge

Submitted by

WALTER A. SPERRY, *Superintendent*
Aurora, Illinois

Figure 2 gives the dimensions and construction details for a Standard U. S. Weather Bureau Rain Gage. It is preferably made of stainless steel and any good tin shop craftsman can make it. Butt and strap joints for all cylindrical sections are recommended since the exact diameters necessary can not be obtained with the lap seam usually used. For this reason the exact widths of the several sheets are given.

The inner gaging can is exactly one-tenth the area of the collecting funnel. Therefore, 1 inch of rain in the gaging can represent 0.1 inch of rainfall; 0.1 inch in the gage represents 0.01 inch of rainfall, etc. A ruler with a "wetting" surface graduated in inches and tenths should be used. This can best be obtained from the Taylor Instrument Company, Rochester, New York. Official rainfall observations are always taken at 7 P.M. and represent the preceding 24 hours.

During the winter period the funnel and inner gaging can are removed. Any snow or ice collected is melted and recorded as equivalent rain. Approximately 10 inches of snow is equal to 1 inch of rain. It may vary, however, from 6 to 25 inches, per inch of rain.

It is important to place the gage about 15 inches above the ground and well away from the influence of trees, shrubbery, or buildings.

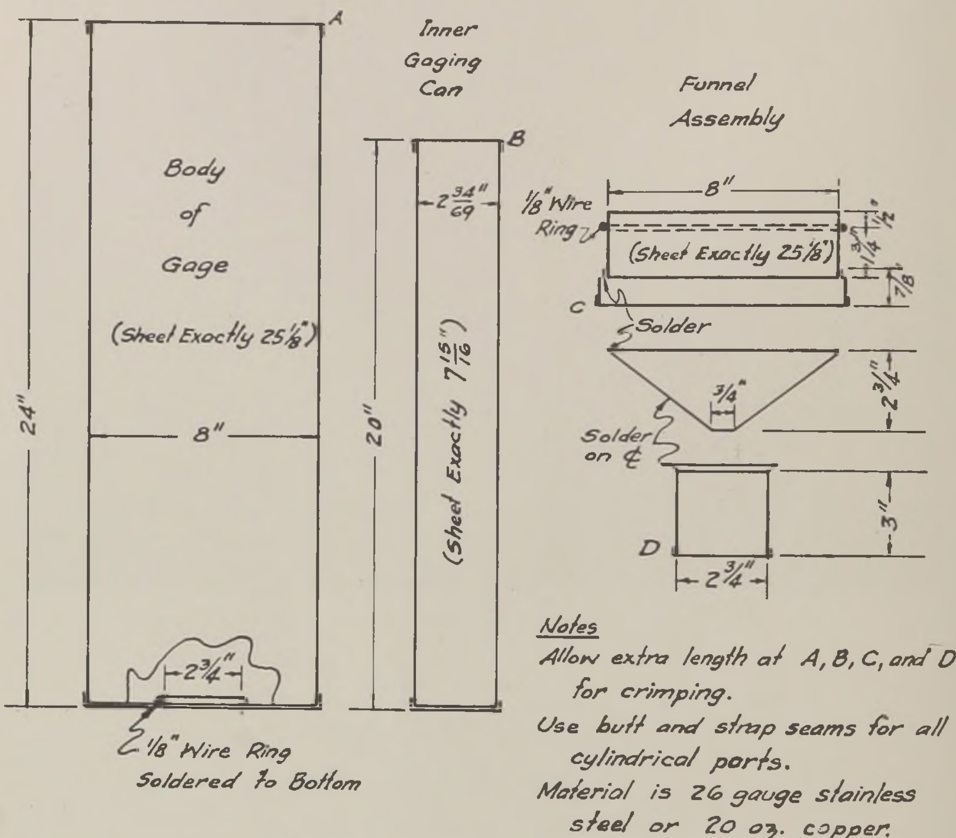

Fig. 2.—Dimensions and details of standard rain gage. Submitted by W. A. Sperry, Supt., Aurora, Illinois.

Rag Press for Screenings

Submitted by

Thomas M. Gwin, *Sewerage Supt.*,
Folsom Prison, California

Operators of sewage works serving institutions should be interested in the rag press (Fig. 3) used at Folsom Prison to dewater screenings prior to incineration. Typical of institutional plants, scraps of clothing, towels, socks, handkerchiefs, tobacco sacks, etc. are removed from the screen in large quantities each day. Quoting Superintendent Gwin:

> It may be of interest to know that the inmates of this institution purchase approximately 17,500 sacks of granulated tobacco each month and most of these sacks find their way to our treatment plant. It seems that whenever an inmate has anything at all which he wishes to discard, he will invariably throw it into the water closet in his cell.

As the screenings are raked from the screen, they are placed into the press. When dewatered, they are taken directly to the dutch-oven type incinerator which performs its function quickly and efficiently due to the preliminary dewatering.

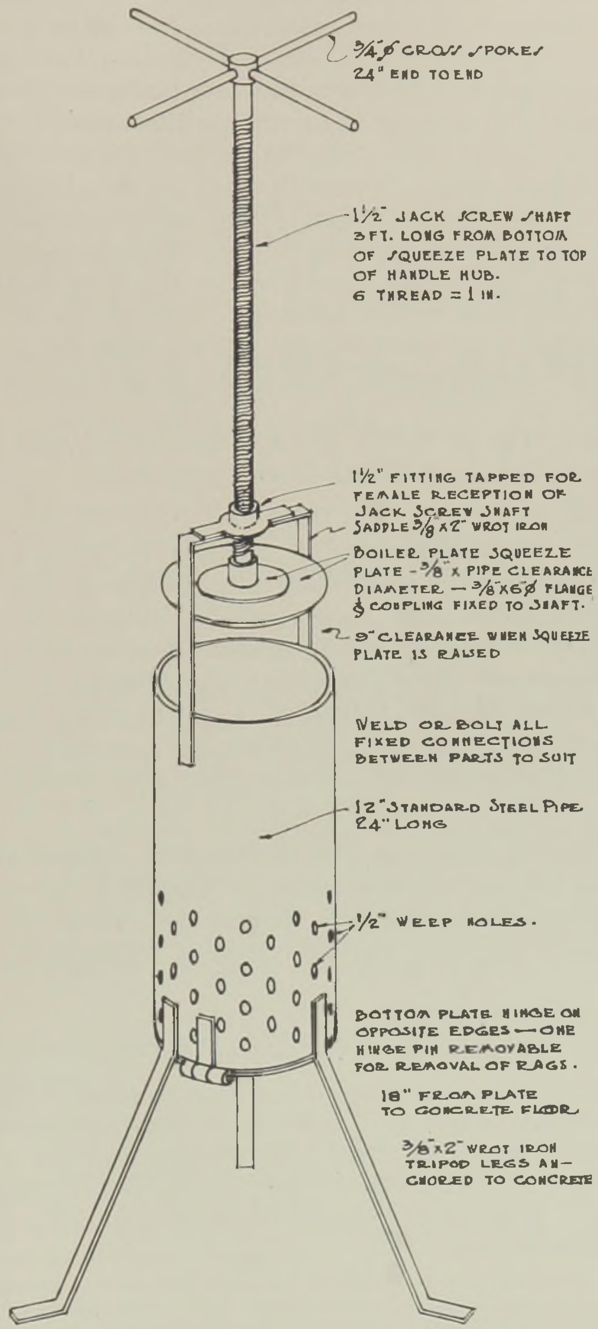

FIG. 3.—Rag press used at Folsom State Prison, California, for dewatering screenings. (T. M. Gwin, Sewerage Superintendent.)

TIPS AND QUIPS

By O. P. Rator

For some time it has been amusing to note the evolution in names assigned to discussions of operation problems in sewage works meetings. From the early "Question Box" came the "Round Table" which, with the operation man's usual efficiency, was eventually put to the dual purpose of holding food, and the "Operator's Breakfast" (or luncheon) came into being. Next came the "Operation Clinic," possibly suggested by occasional cases of overeating at the meal-time discussions. The current trend has been borrowed from radio, as witness the Illinois Conference of Sewage Works Operators "Whizzard Quiz" and the "Court of Appeals in Session" featured by the New England Sewage Works Association in a recent meeting. Both of the latter utilize a group of "experts" (out-of-town operators) with the New England "Court" actually providing for cash prizes to anyone who can stump the "Judges."

Too bad that "Pot O' Gold" already identifies a quiz program—it would have been most appropriate in our profession!

* * * * *

Now comes "Hypo-Fermento"! Alleged to have extraordinary properties in reducing sewage solids to nothingness, this streamlined elixir with a streamlined name was purchased and tried in several sewage works in the Dakotas—but the promised miracles did not take place. The silvery-tongued but elusive salesmen who dispensed the magic fluid (at $40.00 per gallon) despite warnings issued by State Health Departments, may have the opportunity of experimenting with its effect as a reducing agent on jail sentences—if and when apprehended!

* * * * *

The commendable ability of Frank Woodbury Jones of Cleveland, Ohio, to intermingle logic, poetry and philosophy in his practical discourses on sewage treatment, has moved the Pennsylvania Sewage Works Association to create the new office of "Chaplain" for him to assume.

Page Deacon Jones, please!

* * * * *

According to Illinois' *Digester*, to find Superintendent Homer Fisher of Benton, Illinois, grimacing in his mirror does not mean that he is rehearsing a performance as Dracula. It seems that the silver fillings in his teeth afford a means of detecting a surplus of hydrogen sulfide about the plant. When the fillings turn black, he knows the time has come to start chlorination!

* * * * *

The Digester also relates an incident indicating that the common small-town practice of assigning operation of the sewage plant to the

Village Marshall may have one advantage to compensate in part for the many disadvantages. Operator-Marshall Stegler at Cobden, Illinois, was able to curb permanently use of the trickling filter distributor as a merry-go-round by placing several oft-warned, youthful culprits in the town "cooler" for an afternoon!

* * * * *

An unusual method of controlling pooling of trickling filters due to heavy surface growths of filamentous organisms is suggested by Superintendent H. I. Kurtz of Butler, Pennsylvania:

A mild case involving about one-fourth of the filter surface was promptly relieved by application of hydrated lime to the filter influent at the rate of 300 pounds per acre of filter, on two successive days. Kurtz attributes dispersement of the growths to the abrupt increase in alkalinity.

For severe pooling, uniform scattering of 750 pounds per acre of dry hydrated lime over the surface is recommended, followed by 24 hours of rest before operation is resumed.

* * * * *

The following experience of one of the ships employed in carrying sludge for disposal at sea by the Rivers Department of the City of Manchester, England, is noted in the 1939 annual report of that Department:

On Friday, 14th October, 1938, when proceeding on the inward journey via the Rock Channel in half a gale, the sludge steamship "Mancunium" sighted a small open boat in the vicinity of the Tongue Buoy, near the Bar Lightship, at 2–40 p.m. The boat contained three young men who were making signals of distress. The ship rounded up and hove to, picked up the men and the small boat, and resumed course and speed at 2–55 p.m. The three men (William Williams, Ronald Jones, and Neil Matthews) had left Old Colwyn 18 hours earlier. The Llandudno lifeboat had been launched on the disappearance of the men being reported, but failed to find any trace of the boat. The latter was 12 feet long, was waterlogged, the oars had been lost in the heavy sea, and the three men were completely exhausted and quite helpless when picked up, and had to be lifted aboard "Mancunium," where they were provided with food and put to bed.

The Secretary was instructed to convey to the Master of "Mancunium," Captain Charles W. Graham, R.N.R., the thanks and congratulations of the Rivers Committee for the promptness displayed by all parties concerned in the rescue.

* * * * *

From "News Broadcast," published by the New York States Sewage Works Association:

It has always been a question to a lot of us as to the kind and quality of effluent to be expected from a well operated sewage treatment works. Well, of course, we can't expect to produce drinking water but there's no harm in trying.

Now down in Chatham, it seems that Charlie Lose, the operator of that plant, is doing a job to be proud of. In fact he is doing such a good job that the fish, trout mind you, prefer his final settling tank to the stream.

It seems that last spring, Lose had a hundred or so trout living in his final settling tank. Now, the State Department of Health requires chlorination of the effluent at that plant from May 15th to September 15th and Lose wanted to know how about his trout when he started to chlorinate. He was advised to get in touch with the Conservation

Department and see what they had to offer. So a Conservation man came down and together they caught a few trout in nets. But they decided that was too big a job, so left the rest. And the only thing Lose could do was chlorinate. Well, before there was sufficient chlorine residual in the effluent of the final tank to be measurable, the trout started jumping the outlet weir and getting back to the creek.

Maybe this is the answer to our question regarding the kind and quality of effluent to be expected from a well operated sewage treatment works; one that the fish prefer to the receiving stream.

CANADIAN ASSOCIATION DISCUSSES OPERATION PROBLEMS *

Disposal of Wet Sludge

H. S. Nicklin (*Chairman*), *City Engineer, Guelph.*—This discussion refers primarily to the removal of sludge in water-tight tanks, as begun in London in 1936 and at Guelph in 1938. In the former case it seems to be the most economical method; at Guelph it was used for odor control where open beds are in use. The cost was found to be about the same as for other methods.

Question 1.—"Is it feasible to dispose of sludge without dewatering it, and how does the size of the municipality affect this?"

L. T. Robertson, *London.*—Here the sludge is settled 10 to 12 hours in tanks. The liquor is decanted, and the sludge is taken to farms in tank trucks of 5 yards capacity. In 1939 the moisture content was 93.4 per cent and 28,973 cubic yards were removed. In 1940 the moisture has been 93.5 per cent.

Cost figures for 1939 were, on 1647 tons of dry solids, $4.92 per ton. In 1940 up to September 30th, 19,495 cubic yards of wet sludge or 1043 tons of dry solids have been removed—cost $5.23 per ton of dry solids. The size of municipality governs its feasibility as well as the kind of sewage. The lower the moisture content, the lower is the cost.

Mr. Nicklin.—The wet summer of 1940 made drying difficult on open beds.

W. H. Riehl, *Stratford.*—Stratford has been thinking of removing the sludge in wet condition. Tests show that a moisture content of 95 per cent or less can be secured. Hauling would be more expensive than removal of dry sludge, but the cost of preparation would be less. Believed it would be feasible to draw the sludge away at a moisture of 95 per cent, but wet weather might interfere with distribution on the land.

Question 2.—"What equipment and procedure is best suited for handling wet sludge?"

I. F. Robinson, *London.*—In his contract work he uses a tank body 6½ feet wide, 8 feet long and 3 feet deep, holding 5 cubic yards. The opening at the back is 9 inches high. There are 4 locks on the tail gate, to prevent leakage. Body is all welded. An oval shaped tank would be better. Bodies last about 3 years.

Question 3.—"How does the cost of handling wet sludge compare with that of other methods? Is it preferable to partly dewater the sludge first, and what method is best?"

L. T. Roberton, *London.*—Different methods were tried. Filters were used for 1½ years, but the costs were incomparable with removal in tanks. Odor complaints occurred when using the filters. Difficulties were experienced with filter cloths. Ferric chloride was used as a coagulant but large quantities were required. Ferric chloride and lime was better, but the cloth lasted only about 50 hours.

The wet sludge method has been used since 1936, and it is cheaper. The South End plant, receiving only domestic sewage, is more difficult to get a low moisture content. The cost is influenced by continuous or intermittent operation of trucks.

* From Proceedings of The Canadian Institute on Sewage and Sanitation, Toronto, October 24, 1940.

E. H. MUNROE, *York Twp.*—The 1939 cost for haulage of filtered sludge to farms was $1.72 per ton, dry weight.

E. M. BAIRD, *Scarboro Twp.*—Vacuum filter is in operation. There are about 2100 sewer connections, and a population of 10,000. In 1939 there was 1100 cubic yards of dewatered sludge, 83 to 84 per cent moisture. The cost of filtering including chemicals is about $1.00 per cubic yard, and haulage cost is about 50¢ per yard.

DR. W. L. MALCOLM, *Ithaca, N. Y.*—What is done in winter?

H. S. NICKLIN.—It is not feasible at all times. In London it has been used 9 to 10 months. In Guelph the period is 7 months, but this may be extended this winter if weather permits.

W. L. MALCOLM.—What is done during the other months? What storage is required, and how is the cost figured?

H. S. NICKLIN.—In 1938 the Guelph cost for handling sludge on open drying beds was $274 per month. In 1939 the cost for haulage was $250 per month of haulage, and in 1940 for 5 months is $279 per month. While the cost is about the same the tank removal has eliminated the nuisance of odors on the beds.

I. F. ROBINSON, *London.*—An attempt has been made to organize the farmers for winter. We feel that it can be done all year if it is necessary.

WM. STORRIED, *Toronto.*—Long Branch and York Twp. dewater sludge on filters. They can only store the sludge for 3 or 4 days, and it is necessary to haul it away all winter. No particular difficulty has been experienced in the last 4 or 5 years.

H. S. NICKLIN.—The demand for wet sludge will likely outweigh the supply soon.

Question 4.—" How are farms selected for disposal of the sludge, under winter and summer conditions? "

E. H. MUNROE, *York Twp.*—Under the present methods used the farms are semi-urban, possibly 4 acres in size. Selection is based on demand. The farmer must contract to plow in the sludge after delivery. In winter it is spread, and left to be plowed in during the spring.

Question 5.—" What precautions are necessary in using sludge to avoid public health dangers and complaints? "

WM. STORRIE, *Toronto.*—It is doubtful if people realize the precautions that should be observed. There are two types of sludges, digested and undigested. For the latter, the utmost precautions should be taken. Root crops such as celery, radishes and lettuce which will not be boiled before eating, should not be fertilized with raw sludge. Undigested sludge should be plowed in immediately to avoid odors. The North Toronto digested sludge has been used on the Exhibition grounds without complaints.

(He asked the Secretary if any action had been taken to amend the Public Health Act for the control of sludge on land.)

A. E. BERRY, *Toronto.*—The only action taken has been to advise municipalities that sludge should not be used on growing root crops. Little objection is seen to applying the sludge in the fall or in the spring.

WM. STORRIE, *Toronto.*—There is a danger from sludge placed on the ground even in winter as the organisms will survive a long period.

A. E. BERRY.—Agreed that organisms may live for a long period under winter conditions, but they tend to die out rapidly in warm weather.

C. E. NECKER, *Waterloo.*—Sludge can be removed more cheaply in winter on sleighs. It is then easily handled. This year has been bad for drying on open beds, with so much rain.

Question 6.—" What is the most effective rate of application of sludge for fertilizer purposes, and what soils are preferable? "

I. F. ROBINSON, *London.*—For heavy land use 5 to 7 loads to the acre for grain crops, and more for hoe crops. On light land use 9 to 10 loads to the acre. There are 5 cubic yards in a load. Found to be a real fertilizer for pasture.

K. THEAKER, *Guelph.*—The amount depends on the condition of the land. For corn it is put on pretty heavy. The farmer has to be advised as to the amount necessary.

Chlorine in Sewage Plant Operation

Remarks by J. B. Baty (*Chairman*), *Kingston.*—Professor Baty introduced this subject and stated that chlorination has been considered as a major process in sewage treatment. At first it was used only as a disinfectant in the effluent. Later its oxidizing properties were recognized in the reduction of B.O.D. Its use became valuable for overloaded plants. The next development was in odor control, where the chlorine was applied to raw sewage or to settling tank effluents ahead of trickling filters. In chemical precipitation the chlorine was found to be an aid to flocculation. It has prevented sludge bulking. Lately it has been used extensively in aero-chlorination for grease removal.

Question 1.—" At what point should chlorine be applied in order best to prevent septicity of sewage?"

R. C. Williamson, *Montreal.*—The logical place is before the sewage is septic. More chlorine is required later and odors may have occurred. Septicity may occur in long sewers and pump wells, or other places where detention occurs. For septicity in an activated sludge plant the chlorine should be added well ahead of the aeration tanks. If chlorine is applied in doses large enough to overcome septicity it seems to peptise the floc, with poor final settling. This is different from the improvement in settling when applied to prevent bulking.

W. W. Watmough, *Hamilton.*—Sewage should be brought to the point of disposal as promptly as possible. When sewage becomes stale, sulfates may be broken down to form hydrogen sulfide. By destroying the sulfate splitting organisms before H_2S is formed a saving in chlorine is effected. In one place the dose was reduced from 75 p.p.m. to 17 p.p.m. Split chlorination can be applied successfully.

L. T. Roberton, *London.*—Started the use of chlorine in 1936 at the West End plant, primarily to control odors in the aeration tanks. It is used at the entrance to the plant, and in the reaeration tanks. Better operation and odor removal occurred. Amount of chlorine used is small in comparison with chlorine demand. It is used from May to October. For 1940 the average dosage for 155 days was 3.91 p.p.m., with the highest month, July, being 5.02 p.p.m. Practically one-third is used at the inlet, and the remainder in the reaeration tanks.

R. C. Williamson.—Has chlorine been tried further up the trunk sewer?

L. T. Roberton.—Not tried, but was proposed, and is intended for next year.

E. H. Munroe, *York Twp.*—Is dry chlorination to be used at the out stations?

J. B. Kinney, *Toronto.*—No advantage in using dry chlorine gas, and some disadvantages. Might use 25 to 35 per cent more chlorine than a solution feed.

R. C. Williamson.—It would not be advisable to add dry chlorine gas to a sewer, without much thought.

Question 2.—" To what extent does chlorine improve the quality of the effluent of an overloaded sewage treatment plant?"

W. L. Malcolm, *Ithaca, N. Y.*—Depends on many factors in the plant. In general it retards bacterial action and reduces B.O.D. There is an optimum amount of chlorine which can be used, and Rudolf's experiments indicate that there is reduction of 2 parts of B.O.D. to 1 part of chlorine added. Chlorine increases the turbidity of the effluent if iron is present, and may cause discoloration.

J. B. Baty.—There is plenty of evidence to show that chlorine has improved the effluents of overloaded plants, when properly applied.

Question 3.—" How can chlorine assist in overcoming sludge-bulking troubles?"

L. T. Roberton, *London.*—Chlorine is used in London for odor control. It has improved the operation, but to what extent is not known, as the dosage used is small. Ferric chloride is used ahead of the settling tanks when bulking is in evidence. Spent yeast from a local brewery caused much trouble, but chlorine has reduced this.

W. H. Riehl, *Stratford.*—No experience with chlorine to control bulking. The nature of bulking does not appear to be well known. Stratford has had experience with sludge rising to the surface, under septic conditions, and once when it is believed there was bulking. In this latter case the plant was by-passed, and the condition disappeared.

R. C. Williamson, *Montreal.*—(Read remarks on this subject prepared by H. A. Faber, of the Chlorine Institute, New York, in which he stated that there is ample evidence that mild chlorination of return activated sludge assists in correction of bulking.) The exact way in which this acts is unknown. The efficacy of 2 p.p.m. of chlorine to the return sludge of the Ward's Island plant in New York has been shown to give better all round results.

W. W. Watmough, *Hamilton.*—H. D. Bell has claimed in an article that the good effect of chlorine comes through the reduction of anaerobic organisms, and the production of aerobic. He claims chlorine is not proven as a positive cure for bulking.

The effect of chlorine on digestion is not noticeable where the chlorine is applied to the sewage rather than the digestion tanks. When added to these tanks it may control foaming by killing off some of the organisms and delaying the process.

Wm. Storrie, *Toronto.*—Was the Stratford condition a sludge blanket rather than septic sludge rising?

Mr. Riehl.—The sludge did not appear to be septic, but was considered to be bulking.

W. L. Malcolm, *Ithaca, New York.*—The term brown sludge may be a misnomer for good results. In the operation of an activated sludge plant for one year he was unable to get any brown sludge, but did have a stable effluent of 28 days. At Durham, N. C., the operator reported the same. The stability of the effluent is the important factor.

His understanding of bulking was that it was in part due to filamentous growths and under-aeration. The characteristics of sludge bulking may vary with different plants. In Stratford the condition reported would appear more to be decomposition.

A. V. Delaporte, *Toronto.*—Under-aeration often causes this condition. Carbon dioxide is generally given off in the early stages of aeration. If this evolution is delayed to the settling tank it produces a bulking of the sludge, by the presence of minute bubbles of gas. Chlorine has been able to correct any cases of bulking which I have seen. The use of liquid chlorine can only be carried to a certain point without peptizing the sludge. Chloride of lime prevents this.

Question 4.—"Does aero-chlorination improve conditions in the activated sludge process?"

R. C. Williamson, *Montreal.*—Aero-chlorination involves the feeding of chlorine gas with pre-aeration of the sewage. This has been found to be capable of removing up to 80 per cent of the grease in the sewage. Grease removal is especially beneficial where activated sludge or biological processes are employed. Only a small dose of about 2 p.p.m. seems to be required.

J. B. Kinney, *Toronto.*—Reported results from three plants in the United States. At Woonsocket 2 p.p.m. of chlorine and 6 minutes contact gave good results. At Baltimore best results were secured with a dosage of 5 p.p.m. and 5 minutes contact. At Lancaster about 2 p.p.m. and a contact of 2 to 3 minutes were employed.

E. H. Munroe, *York Twp.*—This has not been tried at York Twp., although conditions there might justify its use at times.

A. V. Delaporte, *Toronto.*—Some years chlorine was introduced into the air line, but it was discontinued because of corrosion of the pipe.

Question 5.—"Can settled sewage be used for water to operate a chlorinator?"

R. C. Williamson, *Montreal.*—I do not know. It appears to be a question of economics. It might have to be treated before going through the equipment.

J. B. Kinney, *Toronto.*—Yes it can be be used, but whether it is desirable is another matter. Some recent plants have put in filtration equipment for the final effluent. The Easterly plant at Cleveland, the plant at Niagara Falls, N. Y., Tonawanda, N. Y., and the plant at Minneapolis-St. Paul all use the plant effluent for the chlorinating water.

Public Relations

Question 1.—"Is it desirable to set up some code for the staff to secure best public relations?"

W. C. Miller, *St. Thomas.*—A code is neither necessary nor desirable. It might be regarded as an excuse for following a rigid performance when the particular case did not justify this. Many different conditions develop in public offices. It is well to have a staff which can diagnose the case and handle it to the best advantage. The only rule to follow seems to be—" under all conditions do that which appears to be in the best interests of the customers at all times, and be a gentleman while doing it."

Economy and efficiency is not always the desire of the public in his own case, but courteous treatment is always desirable.

W. H. Riehl, *Stratford.*—A set of rules appears to be out of place. It neither fits the staff nor the public.

Question 2.—" How best can the public be kept informed of the work and services performed by your Department? "

N. Macnicol, *Forest Hill.*—Printed material can be issued by the larger municipalities. Keep on good terms with the press. Newspapers form a large part in forming public opinion. Word of mouth publicity is good. All letters should be acknowledged promptly. Take care of complaints as far as possible. Do not be evasive. The telephone should be answered courteously. Follow through all complaints and notify the party. Complaints are handled by duplicate memos.

R. H. Parsons, *Peterborough.*—The local reporter visits the office daily and is given information of interest to the public. Talks are given before service clubs and public groups regarding municipal works. These talks are effective.

M. P. Adams, *Lansing, Mich.*—An experience in Illinois. W. A. Sperry, Superintendent of the Aurora Sanitary District, has attempted successfully to get before the public the necessity for, and how the municipal utility operates. Emphasis is placed on having school classes visit his sewage treatment plant. Charts are prepared to aid in this. Newspaper contacts are important in state as well as municipal work.

Controller Clarke, *Hamilton.*—A council will only vote for a project which has public support. Department officials should not be too technical in dealing with the public; use human interest contacts. Talks should be made interesting to the public, and they should know what is going on in the municipality.

Question 3.—" What do you do or recommend for improving public relations in your municipality? "

H. S. Nicklin, *Guelph.*—Courteous treatment should be given to all complaints. If it is not possible to rectify the complaint a proper explanation should be given. Ratepayers are generally reasonable when given an explanation.

S. Shupe, *Kitchener.*—Public is inclined to misinterpret the work of the engineer, and think he is not busy when he is formulating plans for projects. The press can be most helpful.

Question 4.—" How are complaints handled? "

R. J. Desmarais, *Windsor.*—The municipality receives complaints, requests for service, and notices of dangerous conditions. All are handled in much the same way. Services should be given where feasible. Complaints are followed by memos in duplicate.

R. O. Hawtrey, *York Twp.*—Ratepayers are sometimes inclined to ask the Department to do things which are illegal, such as doing work on private property.

S. Shupe, *Kitchener.*—The engineer's department cannot do private work. To avoid embarrassment the council some time ago passed a resolution prohibiting this or loaning equipment.

F. P. Adams.—The loan of equipment to contractors can be a reciprocal matter. A hard and fast rule is not always feasible.

Question 5.—" How can municipal Departments best maintain contact with councillors and elected representatives to ensure that the work of the Departments is understood "?

W. L. McFaul, *Hamilton.*—Desirable to maintain a ready access to the engineer's office for all elected officials. Inspection should be made at least once a year by the committee of the council of all works. For new works the inspection should be made as often as needed. The press should be maintained on good relations, and information given on different projects. Nothing should be given to the press before it is presented to the municipal body. Work of major importance might be discussed with some members of the council before it is presented to that body.

SUGGESTIVE SHORT STORY

Bright idea
Works like charm.
Sent to "Corner"
While still warm.

Readers note and
Copy same—
Gadgeteer wins
Lasting fame!

EDITORIAL

ALTERNATING FILTERS IN ENGLAND

One afternoon late in July, 1938, approximately one year before the war began, I had the pleasure of visiting the Birmingham Sewage Treatment Works with Mr. W. C. Whitehead, long known as Chief Engineer of this largest trickling filter plant in the world. Mr. Whitehead and I saw the acres of filters at Minworth, then he showed me four circular filters that were being prepared for large-scale tests of alternating operation, similar to the procedure developed by the Water Pollution Research Board from 1933 to 1938 for dairy wastes at Ellesmere. The filters were 115 ft. in diameter (Figs. 1 and 2) consequently it appeared that the tests would be made on a scale large enough to be convincing, in accordance with all of Mr. Whitehead's work. The Birmingham Board equipped the filters with distributors and all necessary appurtenances, provided excellent laboratory accommodations, and turned the plant over to the Water Pollution Board for operation in October, 1938.

After visiting the filters, we stopped at Mr. Whitehead's quiet study, on the plant grounds, for tea and a discussion of the experiments to be undertaken. The peace of that study has probably been disturbed since then by sirens and bombs, but war or no war, the experiments were carried through and the results reported. The Institute of Sewage Purification, in its meeting at Manchester last July, heard the report as presented by J. M. Wishart and R. Wilkinson—"The Purification of Settled Sewage in Percolating Filters in Series, With Periodic Change in the Order of the Filters," plus a supplementary report by T. G. Tomlinson on biological studies. The authors were in charge of the work and were members of the Water Pollution Research Board, under Dr. A. Parker and Dr. H. T. Calvert, of the Ministry of Health. Preprints of the papers have been received, as well as voluminous notes on the discussion that followed their presentation. The occasion must have been of great distinction, in view of the presence of most of the best-known engineers and chemists associated with sewage disposal in England.

The paper by Messrs. Wishart and Wilkinson may be abstracted briefly as follows:

Four filters were available, each 115 ft. in diameter and 6 ft. deep. The media for Filters *A*, *C* and *D* ranged from 1 to 2½ inches in diameter, but that for Filter *B* contained fine stone (less than 1 inch diameter) in the upper layer. The latter filter soon clogged and was abandoned. The filters were followed by settling tanks which provided 7 hours detention at a rate of treatment of 100 Imp. gal. per day per cubic yard of filter medium (1,161,600 U. S. gal. per acre per day).

Filter *A* was operated as a single unit, Filters *C* and *D* in series, with alternation every seven days as primary and secondary filter. Filter *A* operated at 56 to 81 gal.

per cu. yd. per day, Filters C and D at 60, 90, 120 and 163 gal. per cu. yd. per day. As there was twice as much stone in C plus D as in A, these rates are doubled as applied to Filter C or Filter D. The results of treatment, as summarized in six periods from July 12, 1939 to Aug. 11, 1940, were as follows:

Results	Period					
	1	2	3	4	5	6
Rate of Treatment						
Imp. gal. per cu. yd. per Day						
Filter A	60	59	56	59	67	81
* Filters C and D	90	91	94	121	120	163
Million U. S. gal. per Acre per Day						
Filter A	0.697	0.685	0.650	0.685	0.778	0.941
* Filters C and D	1.045	1.057	1.092	1.405	1.393	1.893
5-day B.O.D., P.P.M.						
Settled Sewage Applied	145	165	180	145	155	155
Settled Effluent, Filter A	7.0	13.5	15.5	13.5	20.0	16.5
Settled Effluent, Filter C	15.0	17.5	22.5	15.5	15.5	18.5
Settled Effluent, Filter D	12.5	10.0	9.0	10.5	20.5	19.5
Suspended Solids, P.P.M.						
Settled Sewage Applied	—	69	87	56	51	54
Settled Effluent, Filter A	9	17	17	22	12	10
Settled Effluent, Filter C	15	11	14	9	9	9
Settled Effluent, Filter D	18	12	11	12	8	10

* Based on area of two filters; double this rate on each.

These results show that the two filters in series were able to treat twice as much settled sewage per cubic yard as the single filter (Periods 4, 5 and 6) and, with exception of the B.O.D. for Period 6, produce a better effluent. The high B.O.D. for the effluent of Filter D in Period 6 was found to be due to oxidation of ammonia nitrogen. When the filters were reversed each week, the B.O.D. of the primary filter effluent became progressively less, whereas that of the secondary filter increased during the latter half of the week, in warm weather (Period 6, from June 10 to Aug. 11, 1940). For one or two days after reversal of the filters, there was no change in the appearance of the surface, but during the remainder of the week, the growth on the surface of the secondary filter rapidly disappeared. Meanwhile the growth thickened on the primary filter.

The two filters in series discharged humus constantly, whereas Filter A unloaded between February and May. The alternating filters were cleaner at the end of the tests than at the beginning.

In order to study the effect of more frequent alternation of filters, as well as other operating variables, eight smaller filters have been built to continue the studies.

Mr. Tomlinson reported in great detail on the biological aspects of the investigations:

Fusarium and *Sepedonium* were found to be the predominant fungi, and they constituted a large part of the thick mats of growth on the surface of the single Filter A and the primary Filter C or D. There was considerable ponding on Filter A from September to May, but any incipient ponding on either of the two filters in series quickly disappeared when the order was reversed. The disintegration of film was ascribed primarily to biological changes induced by the secondary effluent, inasmuch as treatment with distilled water in the laboratory did not loosen the film.

Photographs taken in company with Mr. Whitehead, July 28, 1938.

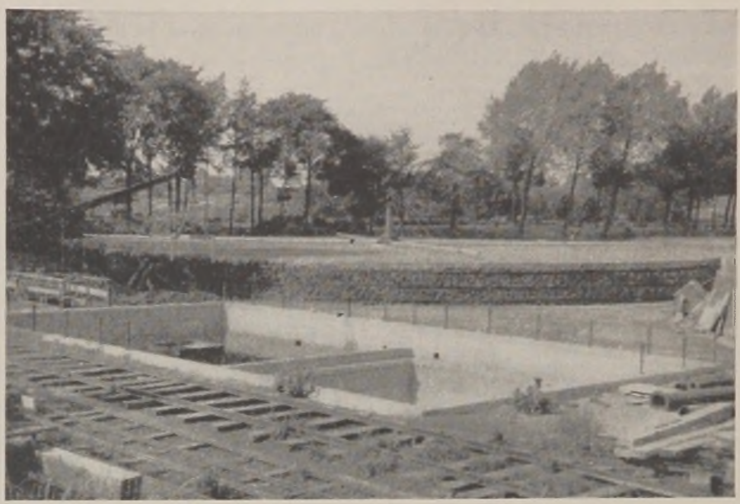

FIG. 1.—One of the Experimental Filters, Settling Tank in Foreground.

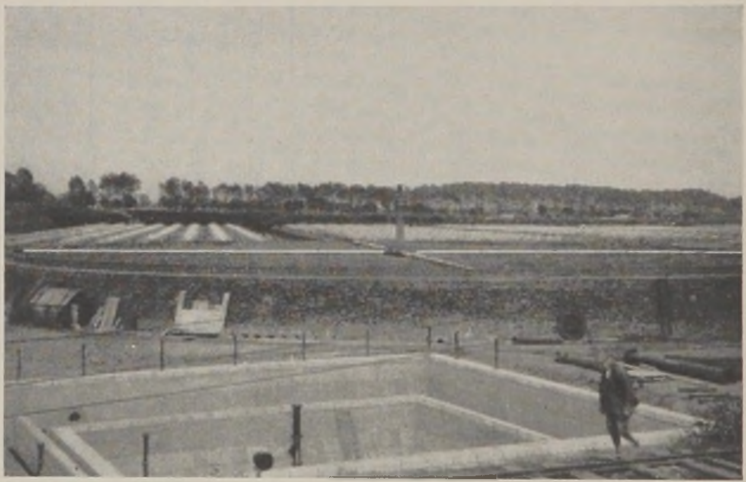

FIG. 2.—Another Filter and Settling Tank, Birmingham Filters in Background.

Following the presentation of these papers, a very extended and informative discussion ensued. The discussion runs some fourteen thousand words, of which only a brief abstract can be reported:

Mr. H. C. Whitehead, who contributed so generously to the experiments, said that in his opinion this work might in the course of time be found worthy to rank with the historic work of the Royal Commission on Sewage Disposal, and of the Massachusetts State Board of Health. It was interesting to recall that the percolating filter was first developed in England by Joseph Corbett at Salford, and that the historic paper by Ardern and Lockett on the activated sludge process was also presented at Manchester. With reference to the practical side of the experiments, his Board owned bacteria beds to the value of £900,000, therefore it was worth while to spend £10,000 to find out if their future extensions could be cheapened. Alternate filtration requires about 7 hp. per million gallons, roughly half that to give partial treatment by the activated sludge process.

Mr. J. J. Thompson, of Leeds, said that the experiments indicated that twice the volume of sewage could be treated per cubic yard of media by alternate operation of filters in series, on Birmingham sewage, but he questioned whether the same conclusion would hold for other sewages, particularly if weaker than at Birmingham.

Dr. E. Ardern, of Manchester, said that the alternation of filters undoubtedly greatly disturbs the biological conditions, resulting in a variable effluent. Although the average B.O.D. might comply with the Royal Commission Standard of 20 p.p.m., he was not sure of the view a Rivers Board would take in respect to the times when this value is exceeded.

Mr. W. T. Lockett, of the West Middlesex Works, stated that the B.O.D. test at his plant frequently included oxygen used for oxidation of ammonia nitrogen, so that he had at one time a B.O.D. of 31.4 p.p.m., of which 22.4 p.p.m. was used to oxidize ammonia and nitrite nitrogen, and only 9.0 p.p.m. was needed for the actual polluting matter present. As a result of this and other similar instances, he had rejected the test. He went on to discuss the clearing up of surface growths on the primary filter, and wondered whether oxidation of fatty matters in the surface mat might account for this phenomenon.

Dr. A. Parker, of the Water Pollution Research Board, who directed the experiments, said that the cost of alternate filtration would be justified even if the volume treated per cubic yard were increased only 25 to 30 per cent, whereas the results showed that the amount treated per cubic yard could be increased 100 per cent. The procedure of alternating filters had already been applied at factories, with considerably greater savings than the entire costs of the experiments. The biological work seemed to indicate that it might be better in summer to change the order of the filters at intervals of one or two days instead of every week. The eight small filters were being used to investigate cycles of one, three and seven days. Two primary filters to one secondary were being tried. Mr. Thompson had referred to the need of organized research in sewage treatment. The Water Pollution Board had plans for constructing a central research building, and money available to start construction in November, 1939, but the project had to be postponed owing to the war.

Mr. J. Bolton, of Blackpool, was interested to know whether the alternate filters would take three times the dry-weather flow during storms, as required in service.

Dr. W. Watson, of Shipley, who carried on experiments on high-rate filtration with re-circulation of effluent, stated that he considered the dissolved oxygen present in the filter influent to be responsible in large part for the clearing up of the filter, but Mr. Wishart had strongly contested this opinion. Now Mr. Tomlinson has concluded that starvation was the cause of disintegration of the surface film in the secondary filter, but in the Shipley experiments there was abundant food in the applied sewage, and yet the filter remained clean and open. He would not like to say on present knowledge whether alternating double filtration (as used at Minworth) or re-circulation (as used at Shipley) would be the more efficient.

Dr. S. H. Jenkins, of Birmingham, suggested that studies should be made of the effect of fluctuating load, as met in practice, rather than a constant rate of flow, as used in the experiments. He was beginning to wonder whether there is actually very much oxidation in biological filters, or more likely almost entirely biological flocculation.

Mr. J. T. Calvert, of Westminster (son of Dr. H. T. Calvert) asked whether the day of the week had any influence on the results, because of the daily fluctuations in strength of sewage.

Dr. T. B. Reynoldson, of Huddersfield, discussed the biological phases of the tests at length. It seemed almost as if the secondary effluent possessed some factor inhibitory to fungal growth. In experiments at Huddersfield, however (see abstract in this issue) fungi flourished in the secondary beds in winter, but here the permanganate oxygen consumed of the primary effluent was 100 to 150 p.p.m., much more than at Minworth.

Mr. R. Hicks, of Hamilton, made a plea for more complete and informative analytical determinations.

Dr. H. H. Goldthorpe, of Huddersfield, stated that the 5-day B.O.D. of the suspended solids in filter effluents averaged about 0.17 gm. per gm., therefore this should be taken into account in comparing settled and unsettled effluents. (During Periods 2 to 6, inclusive, the samples of all filter effluents were settled 1 hour in the laboratory before analysis.)

Mr. H. Jackson, of Birmingham, said it would be helpful to have a test that would distinguish between the use of oxygen in the filters for producing nitrites, as against that of breaking down putrescible carbon and nitrogenous matter.

Mr. Wishart, in reply, stated that the average power consumption for pumping, at the rate of 160 gal. per cu. yd. per day, was 120 kwh. for a static head of 8 or 9 feet. The maximum rate at which the single filter could be operated was 60 gal. per cu. yd. in winter and 80 gal. in summer. The high B.O.D. of the secondary filter effluent, due to oxidation of ammonia, occurred only in summer. He had found the B.O.D. test to be very useful, if one took into consideration all other factors. In Dr. Watson's work at Shipley, the filter was not cleared by application of settled effluent, but by a great dilution of 15 gal. per cu. yd. of settled effluent to 225 of re-circulated filter effluent. After the filter was clear, the proportion of settled effluent was increased until a B.O.D. of 300 p.p.m. was applied. He did not think the daily variation in sewage strength at Minworth had anything to do with the variation in quality of effluent when the filters were reversed. The oxidation of ammonia in the secondary effluent would occur, in time, after it was discharged to a stream, but it would require considerable study to determine the effect of this oxidation on the dissolved oxygen content of the stream. However, high nitrification in the filter is useful in stabilizing the effluent, although many activated sludge plants function well and produce highly purified effluents which contain little or no oxidized nitrogen.

Mr. Tomlinson stated in closure that the alternation of filters tended to repress too vigorous biological growths, which was desirable. They had no data on the relative merits of the filters as to fly nuisance. He did not believe Dr. Watson had demonstrated that dissolved oxygen in the applied sewage was responsible for clearing the filter. At Minworth, after the filters were reversed, the fungal hyphae of *Fusarium* on the secondary filter quickly became denuded of their protoplasm, and then disintegrated and sloughed off. *Psychoda,* however emerged in greater numbers from the secondary than from the primary filter. The total accumulation of film was less per unit volume of the alternating filters than of the single filter.

The importance of this symposium was thought to warrant this lengthy editorial, which would not be complete without an attempt to interpret the results at Minworth as compared with American practice. It will be noted that the maximum rate reported, Period 6, of 163 gal. per cu. yd. per day, is only 1.89 million gallons per acre per day on both filters, or 3.78 m.g.a.d. on each filter. This is well down in the range of American low-rate filters. The B.O.D. applied at this maximum rate is computed to be only 2,500 lb. per acre, or 417 lb. per acre foot per day. This is a conservatively low loading by American standards, and far below the loadings of from 2,000 to 4,000 lb. per acre foot customary in American high-rate filters. However, the Minworth experiments should not be considered as high-rate filtration, but rather as a procedure for obtaining higher loadings on standard filters, with very little if any sacrifice of quality of effluent. Some of the analyses of secondary effluent reported by Mr. Wishart show around 20 p.p.m. nitrate nitrogen, which is never equalled by American high-rate filters, and practically never by low-rate filters, even if sufficient nitrogen and alkalinity are present in the applied sewage to produce such high nitrates.

The Minworth experiments must therefore be considered as something different from the widespread development of high-rate filtration, in which high quality of effluent is a secondary consideration, but high unit reduction of B.O.D. of paramount importance. For English trickling filters, the Minworth results are of great importance. Whether they will be significant to American high-speed, streamlined development remains to be seen. However, sincere congratulations are offered to the Water Pollution Research Board and to Mr. Whitehead who has just retired as President of the Institute of Sewage Purification (a member of our Federation), for their courageous prosecution of this work in war-torn England.

F. W. Mohlman

Proceedings of Local Associations

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Twelfth Annual Fall Meeting, Providence, Rhode Island, September 19–20, 1941

The Twelfth Annual Fall Meeting of the New England Sewage Works Association was held on September 19–20, 1941, at the Hotel Providence Biltmore in Providence, Rhole Island. One hundred and five members and guests, which included seven ladies, were registered for the meeting, which was the lowest attendance in three years. The proximity of the Federation meeting in New York City in October, 1941, was considered as an important contributing factor to this lowered attendance. A secondary influence of considerable importance was felt to be the national defense program which is keeping many of the manufacturers and consulting engineers busy.

At 10:00 A.M. on September 19, the business meeting was called to order by President Walter J. Shea. The secretary-treasurer read his reports which were accepted. The revised constitution was discussed and a special committee was appointed, consisting of Chairman Arthur D. Weston, Samuel M. Ellsworth, Gordon M. Fair and F. W. Gilcreas, to report back to the membership on the revision of certain articles. These were reported and the revised constitution adopted at the close of the A.M. session on Friday, September 19. A copy of the revised constitution has been placed in the Association records.

The following 1942 officers were elected:

President	Samuel M. Ellsworth, Boston, Mass.
First Vice-President ..	R. H. Suttie, New Haven, Conn.
Second Vice-President	Joseph A. Muldoon, Bridgeport, Conn.
Secretary-Treasurer ..	LeRoy W. Van Kleeck, Hartford, Conn.
Directors	George Craemer, Hartford, Conn.
	James S. Goff, Hyannis, Mass.
	Clarence I. Sterling, Jr., Westfield, Mass.

The first speaker during the Friday morning session was Charles G. Richardson, Manager, Venturi Department, Builders Iron Foundry, Providence, Rhode Island, who spoke on the "Measuring the Flow of Sewage and Sludge." This was followed by a paper on "Experiences with Sludge Elutriation" by George H. Craemer, Superintendent, Hartford Metropolitan Sewage Treatment Plant, Hartford, Connecticut. The concluding morning paper was by Walter Kunsch, Superintendent, Danbury Sewage Treatment Plant, Danbury, Connecticut, on "Separate Sludge Digestion Problems."

Luncheon was served in the Garden Restaurant of the Hotel Providence Biltmore at which Mayor Roberts of Providence gave a brief address of welcome. Comments on the construction and operation of the Cranston and West Warwick activated sludge sewage treatment plants were made by Ralph W. Horne of Fay, Spofford & Thorndike of Boston, Massachusetts, and Joseph A. Graemiger, superintendent, respectively. These comments were followed by an inspection trip to the plants.

The annual banquet was held at the Providence Biltmore Hotel at 7:15 P.M., which was followed by a talk on the international situation by Professor Goodrich of Brown University. This talk was followed by a musical and dancing entertainment.

On Saturday, September 20, the Question Box hour was held following the Association breakfast. This was called the "Court of Appeals in Session" and awards of one dollar were made to Members Foote and Goff, for questions submitted to the judges which were unsatisfactorily answered. The judges included F. W. Gilcreas, J. H. L. Giles and Paul C. Martzell. The jury, passing on the answers given by the judges, included Raymond C. Bugbee, George Craemer and Samuel M. Ellsworth.

The Court of Appeals was followed by a talk by Mr. O. C. Sieverding, Chief Chemist of the Bureau of Laboratories of the Connecticut State Department of Health, on the "Results of Analyses of Connecticut Sewages." Mr. Sieverding presented the information in the absence of Captain C. C. Carson in the U. S. Army and formerly Assistant Director of the Connecticut State Department of Health Laboratories.

A meeting of the executive committee of the Association was held during the late morning before luncheon.

The second-day luncheon was held at 12:00 noon at the Hotel Providence Biltmore. At 1:15 P.M., two buses left for the Quonset Naval Air Station. The air station units and sewage treatment plant were inspected. The buses returned to the hotel at 4:00 P.M. and this concluded the events for the Twelfth Annual Meeting.

Inasmuch as only five ladies attended the first day session of the Association meeting, an abbreviated program was planned for them and they were taken by private taxi to the Old Grist Mill in Seekonk, Massachusetts. This was followed by visits to the Carrington and Pendleton Houses and the City Museum. Several of these ladies attended the evening banquet and entertainment.

LeRoy W. Van Kleeck, *Secretary*

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Fourteenth Annual Meeting, Fort Wayne, Indiana, October 6–7, 1941

The meeting was called to order at the Hotel Anthony in Fort Wayne on October 6, 1941. The total registration was 117 members and guests.

President Larson presided and Mayor Harry W. Baals of Fort Wayne gave an address of welcome to the convention.

The report of the secretary was read and accepted. The treasurer's report was received, subject to the approval of the auditing committee.

The following committees were appointed by President Larson: *Auditing Committee,* comprising Leonard W. Hunt, *Chairman;* John C. Mackin, W. E. Ross and M. L. Robins. *Resolutions Committee,* comprising Dr. W. D. Hatfield, *Chairman;* R. W. Frazier, Carl Carpenter, and John Sager. *Nominating Committee,* comprising George Schroepfer, *Chairman;* Carl Carpenter, J. M. Holderby, and Carl E. Schwob. *Awards Committee,* comprising B. A. Poole, *Chairman;* James A. Drake, Graham Walton, and Dr. W. D. Hatfield.

Technical Program

Reports were received from three state boards of health on the activities of the health departments in regard to sewage and waste disposal. The following papers were presented:

"Sewage Treatment in the National Defense Program," by K. V. Hill.
"Certain Studies in Sludge Concentration," by Prof. W. C. Hoad.
"Plant Design for Dissolved Oxygen," by M. W. Tatlock.
"Operation Results at Gary, Indiana," by W. W. Mathews.
"Preliminary Report of the Standard Methods Committees," by Dr. W. D. Hatfield.
"Sewage Disposal Plants from a Fire Insurance Standpoint," by P. L. Sprecher.
"Physical Description of the Fort Wayne Sewage Treatment Plant," by L. R. Mathews.

The annual banquet was held in the Chatterbox Room of the Hotel Anthony. The address for the evening, "National Defense as Related to Municipal Affairs" was given by Dr. J. Raymond Schutz of Indianapolis. Entertainment by the Dorothy Durbin Studios, consisting of music, songs, and dances was enjoyed by all.

The Operators' Breakfast was held on Tuesday morning and some lively discussion on pertinent subjects took place.

On Tuesday afternoon an inspection trip was made of the new Fort Wayne activated sludge plant.

Awards

The award for the best paper presented at the 1940 annual meeting was voted C. C. Ruchhoft for his paper entitled, "The Rôle of *Sphaerotilus Natans* in Activated Sludge Bulking."

Several gadgets were entered in the competition. First prize was voted to Mr. Paul L. Brunner, Fort Wayne, for his vacuum pump control. Mr. Brunner was given possession of the Mohlman plaque for the year 1941–42. Second prize went to Mr. W. E. Ross, Richmond, Indiana, for his "orifice type portable air meter." Third prize went to Mr. C. K. Cornilsen, Chicago Heights, Illinois, for his pressure differential alarm.

Business Meeting

The auditing committee reported favorably on the treasurer's report which was regularly accepted. The resolutions committee entered a resolution giving a vote of appreciation to all those in charge of the arrangements which made the convention a success. This resolution was adopted and made a part of the minutes.

The constitutional amendments were adopted unanimously, which constitution is in accord with the constitution of the Federation.

A report was read outlining a new method for determining the recipient of the award for the best paper. This new award is to be known in the future as the Radabaugh Award.

The nominating committee recommended the following slate and a motion for unanimous election was regularly passed:

George W. Martin, *President.*
K. L. Mick, *First Vice-President.*
Don E. Bloodgood, *Second Vice-President.*
Dr. W. D. Hatfield, *Third Vice-President.*
E. J. Beatty, *Secretary-Treasurer.*
G. J. Schroepfer, *Director to the Federation.*

Invitations to hold the next annual meeting at (1) Duluth and (2) Minneapolis were received for consideration by the Executive Committee. Arrangements have since been made by the Executive Committee to hold the convention in Minneapolis on June 18–19, 1942. This incidentally is the beginning of the fishing season in Minnesota.

E. J. Beatty, *Secretary*

FLORIDA SEWAGE WORKS ASSOCIATION

Organization Meeting, Gainesville, Florida, April 2–5, 1941

Sewage and waterworks operators attending the Ninth Annual Short Course in Water and Sewage Treatment, held at the University of Florida, Gainesville, Florida, April 2–5, 1941, completed organization of the Florida Sewage Works Association on Friday evening, April 4, 1941.

Officers elected to serve the Association during the first year were: *President,* David B. Lee, Director and Chief Engineer of the Bureau of Sanitary Engineering, Florida State Board of Health, Jacksonville; *Vice-President,* Leland F. Frew, Superintendent, Sewage Disposal Plant, Clearwater; *Secretary-Treasurer,* Sidney W. Wells, Senior Chemist, Florida State Board of Health, Jacksonville.

There are 23 members in the Association in good standing for the fiscal year May 1, 1941, through April 30, 1942.

At the Board of Control meeting on October 11, the new Florida Association was admitted to membership in the Federation of Sewage Works Associations.

S. W. Wells, *Secretary.*

Federation Affairs

SECOND ANNUAL CONVENTION

New York City
October 9–11, 1941

The Second Annual Convention of the Federation of Sewage Works Associations was held in New York City from October 9 to 11, 1941, at the Hotel Pennsylvania. The total number of registrants was 569, which was slightly greater than the total of 555 at the First Convention in Chicago.

The feature of the Convention was the time and attention devoted to operating problems. Two entire sessions were exclusively given over to operators—the first on Friday afternoon, when C. C. Larson led the Symposium on Control and Operation of Sewage Treatment Units, and the second on Saturday morning, when Co-leaders L. W. Van Kleeck and B. A. Poole presided over the Operators' Turn Table, held at the same tables on which the Operators' Breakfast was served. Besides these exclusive sessions, the other technical sessions included a majority of papers dealing with plant operation. The plant operator therefore had his day, in fact, his whole meeting, only slightly interfered with by research or "high brow" papers. The operators showed their appreciation of this attention by attending the Friday afternoon session in large numbers, making it the best attended session of the entire convention.

The program of the Convention follows:

THURSDAY MORNING

October 9, 1941

9:00 A.M. Registration—Grand Ballroom.

TECHNICAL SESSIONS

Presiding: C. A. Emerson

11:00 A.M. Introducing the Second Annual Convention of the Federation of Sewage Works Associations. By C. A. Emerson.
Greetings from New York City. By Richard H. Gould.
Operating Experiences in New York City. By Richard H. Gould.

THURSDAY AFTERNOON

Presiding: H. H. Wagenhals

2:00 P.M. Design of Sewage Treatment Plants to Facilitate Operation. By Stuart E. Coburn. Discussion by Morris M. Cohn.
Effect of Load Distribution on the Activated Sludge Process. By Jack E. McKee and Gordon M. Fair. Discussion by L. S. Kraus.
A Laboratory Study of the Guggenheim Biochemical Process. By Earle B. Phelps and John G. Bevan. Discussion by Harry W. Gehm.
Utilization of Sludge Gas in Moderate Sized Treatment Plants. By George Martin. Discussion by Paul D. McNamee.

Thursday Evening

8:30 P.M. Smoker and Entertainment.

Friday Morning

October 10, 1941

Presiding: C. A. Emerson

9:00 A.M. Operation of Sewerage Systems and Sewage Treatment Works from the Standpoint of National Defense. By Warren J. Scott. Discussion by Paul Hansen.

Operation of Small Pumping Stations. By Grant M. Olewiler. Discussion by J. R. Hoffert.

Industrial Wastes, the Law, and Pollution Control Programs. By Milton P. Adams. Discussion by Charles R. Hoover.

Principles and Factors Influencing Vacuum Filtration of Sludge. By Albert L. Genter. Discussion by LeRoy W. Van Kleeck.

Friday Afternoon

Presiding: A. S. Bedell

2:00 P.M. Symposium—Control and Operation of Sewage Treatment Units. Leader: C. C. Larson.

a. Standards of Successful Operation. By Charles Gilman Hyde.
b. Biological Filters. By M. W. Tatlock.
c. Sludge Digestion. By Guy E. Griffin.
d. Screenings, Handling and Disposal. By Wellington Donaldson.
e. Cold Weather Problems in Canadian Sewage Treatment Plants. By Albert E. Berry.
f. Records. By Roy S. Lanphear.

Friday Evening

7:30 P.M. Dinner Dance and Entertainment.

Saturday Morning

October 11, 1941

8:30 A.M. Breakfast—Operators, Engineers, Manufacturers, Everyone.

9:30 A.M. Operators' Turn Table.

Leaders: LeRoy W. Van Kleeck and B. A. Poole.

1. Grit: Conditioning, Handling and Disposal.
2. Safety.
3. Sewage Plant Housekeeping, Inside and Out.
4. What is Your Unsolved or Most Difficult Problem?

11:30 A.M. Business Meeting—Federation of Sewage Works Associations. *Presiding:* C. A. Emerson.

Reports of Federation Committees.

12:30 P.M. Buffet Luncheon.

Saturday Afternoon

2:00 P.M. Inspection Trip—Bowery Bay Sewage Treatment Plant.

5:30 P.M.—Dinner Meeting—Board of Control, Federation of Sewage Works Associations.

Entertainment was provided for the ladies under supervision of Mrs. C. A. Emerson as Honorary Chairman, Mrs. Karl Mann as Chairman, and eleven members of their Committee. The entertainment included a luncheon Thursday noon at Town Hall, followed by a visit to Radio City or attendance at the Central Music Hall at Radio City. Friday afternoon there was a tea and fashion show at the store of James McCreery and Company. Friday night the dinner dance and entertainment attracted many ladies from New York City and vicinity, in addition to those from more distant places.

The business session Saturday morning was important because it marked the end of the long service of Charlie Emerson as Chairman of the Federation. For nearly fourteen years he steered the course of the Federation, without salary or recompense other than the gratitude of his associates and co-workers. In recognition of his appreciated services, Bill Orchard presented him with a gold wrist watch, the gift of the Federation. At the meeting of the Board of Control that evening, Charlie was made the first Honorary Member of the Federation. At this time he announced the establishment of the George B. Gascoigne Award for meritorious papers or reports presented before the Federation.

Sewage works operators were given recognition at this Convention for long years of service by organization of the "Quarter Century Operators' Club" under the leadership of Frank Woodbury Jones, of Cleveland. There were eight operators present deemed worthy of this recognition, namely:

Julius Bugbee, Providence
Stuart E. Coburn, Boston
John Downes, Plainfield, N. J.
Chas. C. Hommon, Canton, Ohio
Frank Woodbury Jones, Cleveland
Roy Lanphear, Worcester, Mass.
Paul Molitor, Sr., Madison-Chatham, N. J.
Wm. Piatt, Durham, N. C.

Manufacturers' exhibits again captured the attention of all visitors. J. Herman Smith had labored all Wednesday night to complete the booths, and by Thursday morning all exhibits were shining and on parade. A total of 37 exhibitors were present, somewhat less than the 55 present at Chicago, but the unsettled business conditions due to defense priorities accounted for absence of some of the Chicago exhibitors.

The New York Convention will long be remembered for the hospitality and cordiality of the hosts, under Local Chairman Richard Gould and General Manager Arthur Bedell, but primarily it will be classed as the meeting where the plant operator was accorded all possible recognition for his support of the Federation.

The Third Convention will be held in Cleveland next October.

F. W. M.

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MINUTES OF MEETING OF 1941 BOARD OF CONTROL

Hotel Pennsylvania, New York City, October 11, 1941

The regular Annual Meeting of the 1941 Board of Control of the Federation of Sewage Works Associations was held at the Hotel Pennsylvania, New York City, on October 11, 1941. The meeting was called to order by President C. A. Emerson at 5:30 p.m.

Roll call indicated representation as followed:

Present in Person

Affiliate or Office Represented	*Represented By*
President	C. A. Emerson
Vice-President	A. S. Bedell
California Sewage Works Ass'n	A. L. Frick
Central States Sewage Works Ass'n	G. J. Schroepfer
Federal Sewage Research Ass'n	A. P. Miller
Georgia Water and Sewage Ass'n	G. R. Frith
Missouri Water and Sewerage Conf.	G. S. Russell
New England Sewage Works Ass'n	F. W. Gilcreas
New Jersey Sewerage Conf.	W. Rudolfs
New York State Sewage Works Ass'n	N. L. Nussbaumer
North Carolina Sewage Works Ass'n	W. M. Piatt
Ohio Sewage Works Conf. Group	F. W. Jones
Pennsylvania Sewage Works Ass'n	H. E. Moses
Member-at-Large	Langdon Pearse
Member-at-Large	L. H. Enslow
Water and Sewage Works Manufacturers Ass'n	L. E. Rein
Water and Sewage Works Manufacturers Ass'n	W. J. Orchard
Sewage Works Practice Committee	F. W. Mohlman
Publications Committee	F. W. Gilcreas
Research Committee	W. Rudolfs

Present in Person, Acting by Proxy

Affiliate or Office Represented	*Represented By*
Treasurer	W. H. Wisely (For W. W. DeBerard)
Argentina Soc. Engineers, San. Eng. Div.	Frank Bachmann (For E. B. Besselievre)
Arizona Sewage and Water Wks. Ass'n	A. L. Frick (For P. J. Martin)
Dakota Water and Sewage Works Conf.	Morris M. Cohn (For W. W. Towne)
Iowa Wastes Disposal Ass'n	A. L. Wieters (For Max Levine)
Kansas Water and Sewage Works Ass'n	L. A. Young (For Earnest Boyce)
Maryland-Delaware Water and Sewerage Ass'n	David Lee (For H. R. Hall
Michigan Sewage Works Ass'n	G. J. Schroepfer (For N. G. Damoose)
Oklahoma Water and Sewage Conf.	C. G. Hyde (For H. J. Darcey)
Pacific Northwest Sewage Works Ass'n	Max Campbell (For J. W. Cunningham)
Sewage Division, Texas Section, S. W. W. A.	W. D. Hatfield (For V. M. Ehlers)
Member-at-Large	A. L. Frick (For A. M. Rawn)
Water and Sewage Works Manufacturers Ass'n	Frank Bachmann (For D. S. McAfee)

The above representation constituted a quorum. Also present was W. H. Wisely, Executive Secretary.

Reading of the Minutes of the Meetings of the Board of Control held in New York City on January 15, 1941 was dispensed with by consent, these Minutes having been published in the March, 1941 issue of Sewage Works Journal. There were no corrections and the Minutes were declared approved as published.

In brief opening remarks, President Emerson referred to the progress made by the Federation in the past year.

Executive Secretary Wisely distributed copies of a report covering the activities of his office during the period January 15, 1941 to September 30, 1941. The financial summary included as part of the report showed that receipts for the period January 1–September 30, 1941 were $19,813.61 and disbursements for the same period totalled $13,971.24. As of September 30, 1941, accounts receivable were $2,901.29 and accounts payable were $2,507.45. The cash balance on hand at the close of business September 30, 1941 was shown to be $9,430.38, of which $9,361.08 was deposited in the Federation's Chicago bank and in control of the Treasurer. It was pointed out that the present large cash balance will be considerably reduced before the end of the year by cost for printing the November SEWAGE WORKS JOURNAL, salaries and other expenses for operations from October 1 to December 31.

In the absence of Treasurer DeBerard, his report was read by Executive Secretary Wisely. The report showed a bank balance at September 30, 1941 of $9,701.73. Deduction of uncleared checks totalling $340.65 left an unencumbered balance of $9,361.08. It was pointed out that the latter balance was in agreement with the amount shown by the books of the Executive Secretary.

Copies of a statistical report showing a classification of the subject matter content of SEWAGE WORKS JOURNAL for the years 1936–1941, inclusive, were presented to members of the Board by Editor F. W. Mohlman.

The following report was presented by the Executive Committee:

"The Executive Committee, by correspondence and several group meetings of its members residing in the New York City area, has kept in close touch throughout the year with the many features incident to the reorganization of the Federation. It is our belief that the Federation is now in position to be of much greater service to the workers in the sewerage field than ever before.

"In accordance with requirements of the By-laws, we submit a budget for the calendar year 1941 for your consideration, and the following recommendations:

(1) That it is only prudent in face of disturbed national conditions to conserve the present cash surplus in the Treasury as far as is consistent with maintenance of the present activities and a modest program for expansion. This would indicate the adoption of Budget A for 1942, which contemplates retention of the Executive Secretary on a part-time basis and acceptance of the offer of Chemical Foundation to continue in charge of the advertising section of the JOURNAL.

(2) That the efforts of officers of the Federation and of the Member Associations for increase in membership and in the volume of advertising in the Journal should give especial attention to the matter of reinstatement of former members and reawakening of the interest of former advertisers.

(3) That the Board should authorize a continuing Convention Place Committee to make an impartial study of invitations received from various cities to act as hosts to the Annual Convention and to make recommendations to the Board of Control for final decision according to a program

which will provide for a reasonable and equitable rotation of the Convention City throughout the country and guard against selection of a city where hotel and meeting facilities would be inadequate.

(4) That there should be a moderate increase in some of the advertising rates for SEWAGE WORKS JOURNAL, consistent with its value as an advertising medium in the broad field of sewage treatment, and to partially offset rising costs for publication.

(5) That the non-association members, subscription price for the Journal be increased so as to maintain a reasonable differential above the price paid by Association Members.

(6) That the officers consider methods for avoiding conflict between our October Convention date and the meeting dates of the Member Associations. It is suggested that the first half of October be left free for the Federation Convention and that all Member Association Secretaries be requested to advise the Federation Secretary promptly of contemplated or scheduled meeting dates of their respective Member Associations.

(7) That the Board of Control should determine that commercial exhibits at the Convention are to be restricted to organizations holding Associate Memberships in the Federation. It is suggested further that the Executive Committee be instructed to confer with Member Associations, which in past years have had exhibits in connection with some or all of their annual metings, to determine if it will not be advantageous all around to institute regulations governing exhibits at such meetings to conform generally to those in effect for the Federation Convention.

Very truly yours,

A. S. BEDELL
C. G. HYDE
W. J. ORCHARD
W. M. PIATT
C. A. EMERSON, *Chairman*"

President Emerson referred Items 1 to 5 of the report to the incoming Board of Control for consideration. By motions properly seconded, Items 6 and 7 were adopted.

Mr. G. J. Schroepfer presented the report of the General Policy Committee, which was considered by individual items:

"1. *Recognition for Meritorious Papers.*—Some Member Associations now present awards for meritorious papers presented at their meetings. The Committee feels this to be a desirable function and recommends the stimulation of this activity to the end that it will uniformly be adopted by all Member Associations. Furthermore, the Committee believes that the Federation should develop recognition of papers presented at Federation meetings or of those published in the Journal which have been presented either at Member Association or Federation meetings, by awards privately financed, and awarded in accordance with rules set down by the Federation. Suggested awards would be named in honor of such leaders in this field as George W. Fuller, Harrison P. Eddy, George Gascoigne, etc. As a means of advancement of this activity the Committee recommends the appointment of an Awards Committee to set up procedures and rules with the idea of placing this activity into effect at the 1942 meeting, or as soon as approved by the Executive Committee. A further matter meriting consideration by the Awards Committee relates to the recognition by suitable citation of the member performing the most outstanding service to the Federation during the year."

"2. *Certificates for Outstanding Operating Reports.*—The Committee is of the opinion that recognition should be given for outstanding operating reports prepared during each year. A desirable procedure might be as follows:

Member Associations would award certificates to its members according to various size classifications and types of plants. Those reports receiving certification would be submitted by Member Associates to a Federation committee for determination of Federation award. Such citations might include statement of recognition, and be awarded on the basis of a "conspicuous contribution to the advancement and betterment of plant operation and maintenance, which deserves special recognition by this Federation." The highest recognition of those receiving certificates might be in the form of a memorial award (plaque or medal) honoring a highly respected and well-known early operator, or some recognized leader in the training of operators as the late Professor Lewis V. Carpenter. Notification to those honored would include, concurrently, notification of public officials and release to local newspapers. The Committee feels that this activity should be started soon, and recommends action at the 1941 meeting notifying Member Associations of this new activity so that they can set up the necessary local machinery to the end that Federation awards can be made at the 1942 meetings. The Committee further recommends the appointment of an Operating Report Committee of the Federation to carry out the purposes of this recommendation and suggests a budget appropriation of $50.00 for this activity."

It was regularly moved, seconded and carried that these recommendations be adopted and that the incoming President be empowered to appoint such committees.

"3. *Public Relations.*—The Committee feels that the Federation should develop and promote a broad general program of public relations to acquaint the public with the purposes and activities of engineers, chemists and operators engaged in the sewage treatment field. As a part of this general program, a committee on "Publicity and Public Relations" should be appointed by each Member Association to handle matters of local interest in recognition of the accomplishments of its members. In furtherance of this aim the Committee recommends the appointment of a Public Relations Committee and suggests a budget appropriation of $100.00."

Adoption moved, seconded and carried.

"4. *Qualifications for Operators.*—The Committee believes that a need exists for the ultimate establishment of minimal qualifications for operators of various classes of treatment works. These might follow in type qualifications adopted by the Conference of Mayors pertaining to Public Health Officers, engineers and nurses. A desirable activity of the Federation would be the promulgation and promotion of the acceptance of such qualifications on a voluntary basis. The Committee recommends the appointment of an Operators' Qualifications Committee and suggests a budget appropriation of $50.00. In addition to the above activity, this Committee would collect and compile present procedure in various states in connection with licensing of operators, etc., and submit to Member Associations for their use."

Adoption moved, seconded and carried.

"5. *Civilian Defense.*—The Committee recommends the appointment of a committee on Civilian Defense to cooperate with committees of other organizations and with governmental agencies in matters relating to the protection and insured operation of sewerage and sewage treatment facilities. A budget appropriation of $25.00 is suggested for this activity."

Adoption moved, seconded and carried.

"6. *Planning for Post-War Period.*—The Committee recommends the appointment of a Planning Commitee of the Federation to cooperate with planning groups and Federal agencies relative to scheduling needed work in this field in the post-war period, and considers an appropriation of $25.00 as necessary."

Adoption moved, seconded and carried.

"7. *Coordinate Technical Activities.*—The Committee is of the opinion that a desirable activity of the Federation is the promotion and coordination of the technical efforts of the various Member Associations to eliminate needless duplication and maintain high standards of committee endeavor. Certain fields requiring urgent investigation might be indicated. This activity could be undertaken by the existing Sewage Works Practice Committee of the Federation."

By motion, duly seconded, Item 7 was adopted and referred to the Sewage Works Practice Committee for report.

"8. *Publications.*—Serious consideration should be given to the possibility of publishing a Sewage Works Manual, or as an alternate, a series of standards (similar to those published by the American Public Works Association) or an operator's manual. This matter should be referred to the Sewage Works Practice Committee, working in cooperation with the Publications Committee, for report to the Board in the near future."

By motion, duly seconded, Item 8 was adopted and referred to the Publications Committee for report.

"9. *Standard Methods of Analysis.*—The Committee recommends the reappointment of the Federation Committee on Standard Methods of Analysis to work with existing committees of the A. P. H. A. and A. W. W. A. In addition to technical efforts along this line, the Committee activity should be directed toward securing proper recognition of matters in the interest of the Federation and of those in the sewage field."

Adoption moved, seconded and carried.

"10. *General.*—The Committee has considered, and suggests, as subjects for further investigation by the Board of Control and by future General Policy Committees, such matters as the appointment of Federation Committees on Member Associations, Short Schools, Membership Promotion, and one to investigate the possibility of dividing the activities of the Federation into Divisions relating to the various interests of the Members."

By motion, duly seconded, Item 10 was referred to the 1942 General Policy Committee for disposition.

The following Report of the Publications Committee, presented by Committee Chairman F. W. Gilcreas, was adopted by motion, regularly seconded:

"The present Publications Committee was appointed at the Annual Meeting of the Board of Control in January, 1941. The Constitution of the Federation of Sewage Works Associations states that this Committee shall arrange the technical programs for the Annual Convention of the Federation, and shall prepare general rules which, after approval by the Board, shall control the preparation, presentation, acceptance, and publication of papers.

"The Committee had little time in which to organize its activities before undertaking its most immediate responsibility—the preparation of the program for the Second Annual Convention. This has been its major accomplishment to date and the result can only be judged by the members' reception of the technical papers and discussions.

"But little supervision of publications of the Federation has been required of the Committee. The Editor and Executive Secretary have undertaken improvements in the format and content of SEWAGE WORKS JOURNAL concerning which no statement by the Committee is needed.

"The establishment of rules and regulations regarding publications has been discussed by the Chairman of the Committee and the Editor, and the Committee submits for the approval of the Board the following rules:

"1. All papers presented before the meetings of the Federation or before any of its Member Associations become the property of the Federation, and publication of these in any but the Federation publications can be made only with specific permission from the Publications Committee.

"2. Papers shall be submitted to the Editor of SEWAGE WORKS JOURNAL in proper form for publication in that JOURNAL. One copy of the paper complete with diagrams, charts, sketches, and bibliography shall be submitted.

"3. The Editor of SEWAGE WORKS JOURNAL shall judge the suitability of any paper for publication. In case any paper is rejected, the Editor shall notify the author within thirty days of the reasons for rejection. Should any disagreement between the Editor and author arise regarding publication, the matter shall be referred to the Publications Committee for adjudication and its decision shall be final.

"4. The Editor of SEWAGE WORKS JOURNAL shall make any editorial changes in format or content which he may consider necessary and these shall be referred to the author in galley proof. Objections to editorial changes shall be referred by the author within seven days to the Editor and the Publications Committee and the decision of the Publications Committee shall be final.

"5. The date of publication of any paper shall be left to the discretion of the Editor of SEWAGE WORKS JOURNAL. Any questions regarding date of publication shall be referred to the Publications Committee and its decision shall be final.

"6. Papers for publication in SEWAGE WORKS JOURNAL which have not been presented at a meeting of the Federation or of any member association shall be referred to the Editor for decision as to their suitability for publication. Any disagreement between the author and the Editor relative to the publication of such papers shall be referred to the Publications Committee and its decision shall be final.

"7. Special publications issued in the name of the Federation of Sewage Works Associations shall be referred to the Editor and Publications Committee for review prior to publication.

"Consideration of the appropriation of limited funds to cover postage and similar expenses of the Committee relative to its activities as outlined in the By-laws is requested of the Board of Control.

Respectfully submitted,

Rolf Eliassen
James L. Ferebee
F. C. Roberts, Jr.
W. W. Towne
LeRoy W. Van Kleeck
Charles R. Velzy
F. W. Mohlman, *Editor*
F. W. Gilcreas, *Chairman*"

Dr. W. Rudolfs reported progress in connection with the work of the Research Committee.

Dr. W. D. Hatfield, Chairman of the Standard Methods Committee, reported briefly on the revisions in various analytical determinations which are under consideration. The report was accepted with thanks to the Committee.

Mr. F. W. Jones, Chairman of the Committee on Sewerage Nomenclature, reported that a Joint Committee with the American Society of Civil Engineers and American Public Health Association was being formally organized to function in 1942. The report was approved.

Applications for affiliation with the Federation by the new Florida Sewage Works Association and the reorganized Ohio Conference on Sewage Treatment were presented. By motions, duly seconded, both applications were accepted.

A motion was made, seconded and carried that the following applicants be admitted to the Federation as Associate Members:

Aluminum Company of America
Cambridge Instrument Company
Ralph B. Carter Company
Electro Rust-Proofing Company
Gruendler Crusher and Pulverizer Company
Lakeside Engineering Corporation
Yeomans Brothers Company
Vapor Recovery Systems Company

Under "Unfinished Business," the Executive Secretary gave the final count on the letter ballot amending Article III of the By-laws of the Federation to read as follows:

Section 1. "The status and dues of the different classes of members established by Member Associations, as applied to their members, shall be as determined by the Member Association."

Section 2 (a). "For each Active Member the annual dues shall be three dollars, payable in advance by the Member Associations to the Secretary of the Federation on December 31, excepting that on specific request and with the approval of the governing body or specially designated officers of any Member Association, the dues of Active Members may, for acceptable reasons, be reduced temporarily to one dollar and fifty cents a year up to a limit not exceeding fifty per cent of the total active membership of the respective Member Association.''

Section 2 (g). ''Active Members, paying full dues and Corporate Members of Member Associations, and Associate and Sustaining Members of the Federation, in good standing, shall be entitled to one copy each of all publications that are distributed by the Federation to its members. Active Members paying partial dues shall be entitled to alternate issues of the Journal and to such other publications that are distributed by the Federation to its members as may be determined by the Board of Control.''

Results of the ballot were: Aye—28; Nay—3; Not voting—5, constituting passage of the amendments.

The Executive Secretary read the following letter addressed to the Board of Control:

''*Gentlemen:*

Enclosed is check for $250.00 for establishment of the George B. Gascoigne Award—one of those recommended in the report of the General Policy Committee.

This donation is made on behalf of Mrs. Myra Gascoigne and George B. Gascoigne's former business associates.

It is suggested that this and other awards might well be plaques, medallions or medals, to be awarded each year or in such years as the Committee should decide that presented papers were sufficiently outstanding as to merit awards, and we firmly believe that whatever form the awards may take, they should be adequate reminders of the high purposes and scientific attainments of the men to whom they are dedicated.

Very truly yours,

HAVENS AND EMERSON

Signed: C. A. EMERSON''

Upon motion, duly seconded, the donation to be applied to Federation Awards was accepted with sincere thanks.

President Emerson issued a call for a meeting of the Election Committee and announced that a meeting of the 1942 Board of Control would follow.

Upon motion made, seconded and carried, the Board adjourned *sine die* at 8:10 p.m.

C. A. EMERSON, *President*

W. H. WISELY, *Executive Secretary*

MINUTES OF A MEETING OF THE ELECTION COMMITTEE OF THE BOARD OF CONTROL

Hotel Pennsylvania, New York City, October 11, 1941

At the conclusion of the meeting of the 1941 Board of Control held at the Hotel Pennsylvania, New York City, President C. A. Emerson called to order a meeting of the Directors representing all Member Associations to function as an Election Committee.

Officers present were President Emerson and Executive Secretary W. H. Wisely. Roll call of Directors follows:

Present in Person

Member Association Represented	*Director*
California Sewage Works Ass'n	A. L. Frick
Central States Sewage Works, Ass'n	G. J. Schroepfer
Federal Sewage Research Ass'n	A. P. Miller
Florida Sewage Works Association	David B. Lee
Georgia Water and Sewage Ass'n	G. R. Frith
Missouri Water and Sewerage Conf.	G. S. Russell
New England Sewage Works Ass'n	F. W. Gilcreas
New Jersey Sewerage Conf.	W. Rudolfs
New York State Sewage Works Ass'n	N. L. Nussbaumer
North Carolina Sewage Works Ass'n	W. M. Piatt
Ohio Conference on Sewage Treatment	F. W. Jones
Pennsylvania Sewage Works Ass'n	H. E. Moses

Present in Person, Acting by Proxy

Member Association Represented	*Represented By*
Argentina Soc. Engrs., Sanitary Eng. Div.	Frank Bachmann (For E. B. Besselievre)
Arizona Sewage and Water Works Ass'n	A. L. Frick (For P. J. Martin)
Dakota Water and Sewage Works Conf.	Morris M. Cohn (For W. W. Towne)
Iowa Wastes Disposal Ass'n	A. L. Wieters (For Max Levine)
Kansas Water and Sewage Works Ass'n	L. A. Young (For Earnest Boyce)
Maryland-Delaware Water and Sewerage Ass'n	David Lee (For H. R. Hall)
Michigan Sewage Works Ass'n	G. J. Schroepfer (For N. G. Damoose)
Oklahoma Water and Sewerage Conf.	C. G. Hyde (For H. J. Darcey)
Pacific Northwest Sewage Works Ass'n	Max Campbell (For J. W. Cunningham)
Sewage Division, Texas Section, S. W. W. A.	W. D. Hatfield (For V. M. Ehlers)

The above representation constituted a quorum.

Upon call for nominations for President, A. S. Bedell was nominated and a motion to close the nominations was duly seconded and carried. By *viva voce* vote the election of Mr. Bedell to the office of President was confirmed and was so declared.

G. J. Schroepfer was nominated for the office of Vice-President in response to a call for nominations to that office. There being no further nominations, a motion was made, seconded and carried that the nominations be closed. The election of Mr. Schroepfer as Vice-President was confirmed by *viva voce* and so declared.

In response to a call for nominations to the office of Treasurer, the name of W. W. DeBerard was offered and the nominations closed by passage of a regularly seconded motion. Election of Mr. DeBerard to the office of Treasurer was confirmed by *viva voce* vote and so declared.

Upon call for nominations to the office of Director-at-Large, with term expiring in October, 1944, W. J. Orchard was nominated. Since Mr. Orchard had just completed on abbreviated term as Director-at-Large representing the Water and Sewage Works Manufacturers Association, a question was raised as to his eligibility to reelection as Director (Section 5, Article IV of the Constitution). The view was taken that Mr. Orchard had been nominated to serve as Director-at-Large representing the Member Associations, which did not constitute reelection because of the difference in representation and this stand was confirmed by a showing of hands vote as follows:

Eligible to nomination	11
Ineligible to nomination	5
Not voting	6

The nominations were closed by motion regularly seconded. The election of Mr. Orchard to the office of Director-at-Large was confirmed by a showing of hands vote of 17 Ayes, 1 Nay, 4 not voting, and was so declared.*

Upon motion duly made, seconded and carried, the meeting adjourned *sine die,* at 8:35 P.M.

C. A. Emerson, *President*
W. H. Wisely, *Executive Secretary*

MINUTES OF MEETING OF 1942 BOARD OF CONTROL

Hotel Pennsylvania, New York City, October 11, 1941

Immediately upon termination of the meeting of the 1941 Election Committee, President C. A. Emerson called to order a meeting of the 1942 Board of Control.

Roll call indicated representation as follows:

Present in Person

Affiliate or Office Represented	*Represented By*
President	A. S. Bedell
Past-President	C. A. Emerson
Vice-President	G. J. Schroepfer
California Sewage Works Ass'n	A. L. Frick
Central States Sewage Works Ass'n	G. J. Schroepfer
Federal Sewage Research Ass'n	A. P. Miller
Florida Sewage Works Ass'n	David B. Lee
Georgia Water and Sewage Ass'n	G. R. Frith
Missouri Water and Sewerage Conf.	G. S. Russell
New England Sewage Works Ass'n	F. W. Gilcreas
New Jersey Sewerage Conf.	W. Rudolfs
New York State Sewage Works Ass'n	N. L. Nussbaumer
North Carolina Sewage Works Ass'n	W. M. Piatt
Ohio Conf. on Sewage Treatment	F. W. Jones
Pennsylvania Sewage Works Ass'n	H. E. Moses
Member-at-Large	L. H. Enslow
Member-at-Large	W. J. Orchard
Water and Sewage Works Manufacturers Ass'n	L. E. Rein

* Feeling that his election to the office of Director-at-Large was contrary to the intent of the Constitution, Mr. Orchard tendered his resignation on October 13, 1941. The resignation was accepted and the Executive Committee, in accordance with Section 4, Article IV of the Constitution, has since appointed A. H. Niles to fill the vacancy.

Present in Person, Acting by Proxy

Affiliate or Office Represented	*Represented By*
Treasurer	Langdon Pearse (For W. W. DeBerard)
Argentina Soc. Engineers, San. Eng. Division	Frank Bachmann (For E. B. Besselievre)
Arizona Sewage and Water Works Ass'n	A. L. Frick (For A. M. Rawn)
Dakota Water and Sewage Works Conf.	Morris M. Cohn (For W. W. Towne)
Iowa Wastes Disposal Ass'n	A. L. Wieters (For Max Levine)
Kansas Water and Sewage Works Ass'n	L. A. Young (For Earnest Boyce)
Maryland-Delaware Water and Sewerage Ass'n	David B. Lee (For H. R. Hall)
Michigan Sewage Works Ass'n	G. J. Schroepfer (For N. G. Damoose)
Oklahoma Water and Sewage Conf.	C. G. Hyde (For H. J. Darcey)
Pacific Northwest Sewage Works Ass'n	Max Campbell (For J. W. Cunningham)
Sewage Division, Texas Section, S. W. W. A.	W. D. Hatfield (For V. M. Ehlers)
Member-at-Large	A. L. Frick (For A. M. Rawn)
Water and Sewage Works Manufacturers Ass'n	Frank Bachmann (For D. S. McAfee)

The representation constituted a quorum. W. H. Wisely, Secretary, was also present.

President Emerson requested the Secretary to present the report of the Election Committee which had elected the following officers: A. S. Bedell, President; G. J. Schroepfer, Vice-President; W. W. DeBerard, Treasurer (all to serve until October, 1942); and W. J. Orchard, Member-at Large (to serve until October, 1944).

Mr. Emerson expressed his appreciation for past cooperation by present and former Board members, in relinquishing the chair to President Bedell. Upon assuming the chair, President Bedell directed attention to Mr. Emerson's great service to the Federation and expressed appreciation for the confidence in him evidenced by his election to the Presidency.

In requesting nominations for the appointment of a Secretary, President Bedell suggested that the appointment be made for only one year instead of two years as stated by the Constitution, in view of present, unsettled economic conditions. It was moved, seconded and adopted that W. H. Wisely be reappointed to serve as Secretary under the present half-time arrangement until the close of the next Convention in October, 1942, at a salary of $2500 per year.

By motion, regularly seconded and adopted, Dr. F. W. Mohlman was reappointed to serve as Editor for a three-year term under the same arrangement as practiced since January 15, 1941.

To expedite appointment of the various Constitutional Committees, President

Bedell presented a schedule of recommendations and the following appointments were approved by motions regularly made, seconded and carried:

Executive Committee (President and four Directors)
A. S. Bedell, *Chairman* (New York)
G. J. Schroepfer (Central States)
D. S. McAfee (Manufacturers)
H. R. Hall (Maryland-Delaware)
A. E. Berry (Canada)

General Policy Committee (Latest living Past-President as Chairman, three Directors and three Members-at-Large. Three of total to be operators).
C. A. Emerson, *Chairman* (Past-President)
H. E. Moses (Pennsylvania)
L. H. Enslow (New York and Manufacturer)
L. L. Luther (New York, Operator)
C. G. Hyde (California)
R. E. Fuhrman (Federal, Operator)
N. G. Damoose (Michigan, Operator)

Publications Committee (Editor and at least four Members-at-Large).
F. W. Gilcreas, *Chairman* (New England)
F. C. Roberts, Jr. (Arizona)
W. S. Mahlie (Texas)
R. S. Phillips (North Carolina)
Rolf Eliassen (New York)
J. L. Ferebee (Central States)
W. W. Towne (Dakota)
F. W. Mohlman, Editor (Central States)

Organization Committee (Three Members-at-Large)
G. R. Frith, *Chairman* (Georgia)
F. W. Jones (Ohio)
Earnest Boyce (Kansas)

Sewage Works Practice Committee (Editor and at least four Members-at-Large)
Morris M. Cohn, *Chairman* (New York)
F. W. Mohlman, Editor (Central States)
C. E. Keefer (Maryland-Delaware)
B. A. Poole (Central States)
J. J. Wirts (Ohio)
John Brooks (New England)
G. P. Edwards (New York)
Harold P. Gray (California)

Research Committee (Chairman to be selected by Board. At least five Members-at-Large to be selected by Chairman).
Willem Rudolfs, *Chairman.*

President Bedell called upon Mr. Emerson to discuss the Special Committees, including those recommended by the 1941 General Policy Committee. Mr. Emerson recommended the appointment of an Awards Committee, Operation Report Committee, Publicity and Public Relations Committee, Operators Qualifications Committee, Civilian Defense Committee and Post-War Period Planning Committee in addition to the Sewage Nomenclature and Standard Methods Committees which have already functioned. It was moved, seconded and carried that the President appoint at least five members to each of the above Committees, by and with consent of the Executive Committee, in the near future.

Mr. Emerson referred to the Convention Place Committee recommended by the 1941 Executive Committee and offered the following resolution which was duly seconded and carried:

> *Resolved*—That there shall be a Convention Place Committee of seven members, consisting of the President of the Federation, who shall serve as Chairman; the Secretary of the Federation who shall serve as Secretary; the Vice-President and the latest living Past-President of the Federation; and the President, the Chairman of the Executive Committee of the Sewage Works Division and the Manager of the Water and Sewage Works Manufacturers Association.
>
> It shall be the duty of this Committee to consider applications and available data relative to selection of the Convention Meeting Place for the ensuing year and to make recommendation for final determination by the Board of Control at its last session during the current Annual Convention of the Federation, if practicable, or in any event not later than sixty days after the close of the Annual Convention.

Mr. Emerson explained the action of the 1941 Executive Committee in authorizing Chemical Foundation to continue the service of Mr. A. A. Clay as Advertising Manager of SEWAGE WORKS JOURNAL and to handle all mechanical details incident to the production of advertising therein. Reference was made to a letter received from Mr. F. P. Garvan, President of Chemical Foundation, in which continuation of these services for the year 1942 for the sum of $1,000.00, plus incidental office expense, was offered. It was regularly moved, seconded and carried that the above offer be accepted with thanks to Chemical Foundation for its continued interest in the Federation.

A proposed increase in advertising rates in SEWAGE WORKS JOURNAL was referred to the Executive Committee for consideration and action.

The matter of increasing non-member subscription rates for SEWAGE WORKS JOURNAL, in view of the increase in Member dues, was afforded considerable discussion. A new, non-member, annual rate of $5.00 was approved, with a special 20 per cent discount to educational institutions, by motion regularly made, seconded and carried.

Following a discussion of the fidelity bonds now carried in the amount of $5,000.00 each on the Treasurer and Secretary, it was the sense of the meeting that these bonds be renewed on the same basis for 1942.

President Bedell recommended the appointment of a special Committee to be designated as the Financial Advisory Committee to function in regard to financial matters incident to the operation of the Federation. Authorization of a Financial Advisory Committee to consist of the President, Vice-President, and W. J. Orchard was moved, seconded and carried.

The Secretary reported that, at the request of the 1941 Executive Committee, he had obtained proposals from two accountants in regard to the annual audit of the Federation's books required under the By-laws. Proposals were presented from George J. Curzon and L. M. Kessler, both of Champaign, Illinois who quoted prices for the audit of $40.00 and $50.00 to $75.00, respectively. President Bedell referred this matter to the financial Advisory Committee with authority to provide for a satisfactory audit.

Mr. Orchard moved passage of a suitable resolution to authorize continuation of the account of the Federation in the Continental Illinois National Bank and Trust Company of Chicago, which motion was duly seconded and carried.

Mr. Orchard moved that the Financial Advisory Committee previously authorized be given power to open such other bank accounts as may be deemed advisable and be further empowered to direct the President to draft necessary resolutions pertaining thereto. The motion was duly seconded and carried.

Mr. Emerson presented a letter received from Mr. A. T. Clark, Manager of the Water and Sewage Works Manufacturers Association which advised that an appropriation for the year of $5,000.00 to the Federation's treasury, to be paid in quarterly installments, had been approved by that organization on the same terms as the 1941 agreement. It was regularly moved, seconded and carried that the offer be accepted with thanks to the Association for its continued interest in the Federation.

Upon call for nominations to Honorary Membership, it was moved, seconded and carried that Mr. C. A. Emerson be conferred with Honorary Membership in recognition of his past and present services to the Federation.

President Bedell called for the report of the 1941 Convention Place Committee, which was as follows:

"*Gentlemen:*

The Convention Place Committee has given consideration to the invitations which have been received in behalf of various cities as the meeting place for your 1942 Annual Convention and examined the very considerable quantity of data concerning hotel and meeting facilities which had been submitted.

Invitations have been received from Cleveland, Ohio; Dallas, Texas; Oakland, California and St. Paul, Minnesota.

After careful consideration, we unamiously recommend that in view of present conditions, you select Cleveland as the meeting place for the 1942 Annual Convention and that serious consideration be given to California as the meeting place for the 1943 Convention.

Respectfully submitted,

Convention Place Committee,

A. S. Bedell
A. T. Clark
Karl Mann
D. F. McAfee
Wm. J. Orchard
W. H. Wisely
C. A. Emerson, *Chairman*"

It was regularly moved, seconded and carried that Cleveland be selected as the meeting place for the 1942 Convention. Mr. F. W. Jones acknowledged this action in behalf of the Ohio Conference on Sewage Treatment which will be the host in 1942.

Authorization for the President to appoint a Convention Hotel and Management Committee, comprising five Members, to be charged with responsibility for arrangements and operation of the 1942 Convention, including selection of the date, subject to approval by the Board, was approved by motion, duly seconded and carried.

The three alternate budget schedules presented previously by the Executive

Committee were next considered and the following budget adopted by a motion regularly seconded and carried.

1942 BUDGET

Receipts:		
Member Dues		
1600 @ $3.00	$ 4,800	
800 @ $1.50	1,200	
Associate	1,200	
Non-Member Subscriptions	900	
Advertising (Net)	8,000	
Net Sales Misc. Publications	300	
Exhibit Privileges		
(Water & Sewage Works Mfgrs. Ass'n)	5,000	
Total Receipts		$21,400
Expenses:		
JOURNAL Printing	$11,000	
Editorial Expense	1,400	
Executive Secretary		
Salary	2,500	
Office Salaries	1,400	
Office Expense	750	
Office Equipment	100	
Travel Expense	900	
Exp. Other Officers	500	
Committee Expense	500	
Advtg. Mgr's Expense	1,250*	
Convention Expense	600	
Contingencies	500	
Total Expense		$20,150
Indicated Surplus		$ 1,250

* Not included in Total Expense since already deducted to show net advertising income.

In the discussion of the budget it was suggested that the Secretary investigate the possibility of placing an order through Lancaster Press for sufficient cover and body paper stock to meet the needs of SEWAGE WORKS JOURNAL through the year 1943, even though payment might be required upon delivery of the paper to Lancaster Press. The purpose of this action was to minimize the production cost of the JOURNAL in view of rising paper prices.

It was moved, seconded and carried that the Secretary prepare and direct letters of appreciation and thanks to the Hotel Pennsylvania for assistance rendered in the conduct of the 1941 Convention and to Commissioner Irving V. A. Huie of New York City for his participation in the program of the Convention. A letter expressing hope for an early recovery was also directed sent to Mr. Charles Eastwood who has been unable to continue his active participation in Federation affairs due to illness. Similarly, President Bedell was directed to send a letter of appreciation to the Urbana-Champaign Sanitary District for the facilities allowed for the use of the Federation.

By motion, duly seconded, the meeting adjourned.

ARTHUR S. BEDELL, *President*
W. H. WISELY, *Secretary*

REPORT OF EXECUTIVE SECRETARY
For Period of
JANUARY 15–SEPTEMBER 30, 1941

The past few months have been important ones in the history of the Federation. Adoption of the new Constitution and By-laws by the Board of Control on January 15, 1941 instituted a period of reorganization and transformation which is purposely being developed slowly and cautiously in view of the present unsettled economic situation. Definite progress has already been made; however, several years may be required to completely establish an organization which can fully achieve the aims and objectives upon which the Federation is founded. In the meantime, no effort has been spared to render every service possible with the resources available at this time.

Establishment of Executive Secretary's Office

Immediately following the appointment of the Executive Secretary, arrangements were made to establish the Federation business office at Urbana, Illinois, located 130 miles from Chicago. Permission was obtained to use space in the Administration Building of the Urbana and Champaign Sanitary District without charge for office rental. A full time bookkeeper-clerk and part time office assistant were employed and a few necessary items of office equipment were purchased.

On March 1, the Executive Secretary assumed the duties of the former office of Secretary, held by Mr. H. E. Moses, and all of the duties of Business Manager which were previously handled by Mr. A. A. Clay in the Chemical Foundation, with the exception of work pertaining to procurement of copy from advertisers, preparation of advertising dummy and supervision of the two advertising solicitors then under contract with the Federation. These latter functions were retained by Mr. Clay under the title of Advertising Manager in accordance with an agreement providing that Chemical Foundation be compensated in the amount of $750 plus postage expense for this service during the period April 1–December 31, 1941. Arrangement for Chemical Foundation to continue to handle all mechanical details pertaining to advertising in Sewage Works Journal was deemed advisable by the Executive Committee to enable the half-time Executive Secretary to devote a portion of his efforts to activities of more direct benefit to the membership of the Federation.

The excellent cooperation given by Messrs. Moses and Clay enabled the transfer of affairs to the Urbana office to be accomplished with no interruption in the details of business management.

Since March 1, the Executive Secretary's office has maintained the mailing list for publications, handled billing of non-member subscribers and advertisers, sale of back numbers and "Modern Sewage Disposal," collection of dues and other accounts, keeping of books and financial records, and all similar details of business management as well as other services described hereafter.

Incorporation

In accordance with the action of the Board of Control on January 15, 1941, the Federation was incorporated as a non-profit organization under the laws of the State of Illinois, on February 17, 1941. The articles of incorporation were amended as of April 22, 1941 to include a more complete definition of the objects of the Federation, in an effort to establish exemption from certain Federal taxes.

Bonds for Treasurer and Executive Secretary

In accordance with Sections 4 and 5 of Article IV of the By-laws, fidelity bonds in the amount of $5,000 each were secured from the Hartford Accident and Indemnity Company to cover the activities of the Treasurer and Executive Secretary, which bonds date from January 15, 1941.

ACTIVITIES OF EXECUTIVE SECRETARY

Aside from the conduction of the business affairs of the Federation, as outlined above, the Executive Secretary performed other services in connection with SEWAGE WORKS JOURNAL, promotion of improved relations with Member Associations and preparations for the Second Annual Convention.

Sewage Works Journal

In the meeting of January 15, the Board of Control directed the writer to assist Editor F. W. Mohlman in the production of SEWAGE WORKS JOURNAL and instructed that "every effort be made to make the JOURNAL more attractive to and interesting for the average sewage works operator."

Accordingly, the Executive Secretary undertook conduction of the plant operation section in the JOURNAL which has been designated as "The Operators' Corner," for which copy has been submitted to Editor Mohlman for publication in the May, July and September issues of the JOURNAL. This function has entailed voluminous correspondence to obtain material and considerable time to prepare copy. It is considered sufficiently important to justify such attention, and constructive suggestions or criticisms as basis for improvement will be welcome.

The Executive Secretary has collaborated with Advertising Manager Clay in every possible manner in securing advertising for the JOURNAL. Most of this service has been in connection with the Convention Number (September issue), for which a total of 17$^{13}/_{24}$ pages of additional advertising space was sold. More than 800 communications in solicitation of Convention Number advertising were mailed from this office in accordance with instructions of Mr. Clay. Other advertising was solicited by correspondence and by personal interview, in a few cases.

The combined efforts of Editor Mohlman, Mr. Clay, Lancaster Press and this office resulted in the restoration of the original publication schedule of the JOURNAL. The July and September issues were distributed during their respective months of publication.

Cooperation with Member Associations

In the meeting of January 15, the Board expressed the desire that the Executive Secretary cooperate to the fullest extent in developing close relationship between the Federation and its Member Associations, by personal attendance at Association meetings whenever possible. Under the prevailing half-time arrangement and due to the attention required in establishing the business office, this service was necessarily limited but was augmented to some extent by President Emerson's representation of the Federation at the meetings of the California Sewage Works Association (April 20–22), Maryland-Delaware Water and Sewage Association (May 8–9), and an Executive Committee meeting of the Arizona Sewage and Water Works Association (April 26). Member Association meetings attended by the Executive Secretary follow:

Date	Association	Place
January 16–17	New York Sewage Wks. Assn.	New York City
March 13–15	Kansas W. & S. Wks. Assn.	Lawrence, Kansas
June 18–20	Michigan Sewage Wks. Assn.	Lansing, Mich.
August 28–29	Dakota W. & S. Wks. Conference	Aberdeen, So. Dak.
September 3–5	Pennsylvania Sewage Wks. Assn.	State College, Pa.

In the latter four meetings, facts concerning the reorganization of the Federation were presented at the business sessions at which constitutional amendments were considered. The writer also participated in the technical programs of the Michigan and Dakota meetings. Meetings of the Illinois Conference of Sewage Works Operators (Urbana, March 10–12) and the Wisconsin Sewage Works Conference (Green Bay, May 27–28) were also attended for participation in the technical programs and to present addresses concerning the value of the Federation to those engaged in sewage works operation.

Because available time did not permit attendance of the meeting of the Ohio Conference on Sewage Treatment on September 18–19, a brief, prepared statement pertaining to the aims and motives of the Federation was furnished, to be read at the business meeting at which reorganization of the Conference was to be considered.

Preparation for Second Annual Convention

This office cooperated in every possible way with the Convention Management Committee in the preparations for the Convention to be held in New York on October 9–11.

Among the Convention arrangements handled were the following:

1. Distribution of publicity material among Member Association secretaries, State Sanitary Engineers and other interested agencies.
2. Supervision of printing and mailing of the formal announcement and notice to the individual Association members.
3. Printing of tickets, badges and official program.
4. Furnishing material for Federation booth.
5. Preparation of business for Board of Control meeting October 11.

Membership

The new classification of Associate Member, established in the Constitution and By-laws adopted January 15, 1941, was given considerable attention. Membership in this classification was solicited by correspondence with all Class A and Class S members of the Water and Sewage Works Manufacturers Association and with prospective members of that organization and, as of September 30, 55 Associates have affiliated with the Federation.

The Florida Sewage Works Association, a new organization, has made application for affiliation with the Federation as a Member Association.

Membership in the Member Associations appears to be favorable at this time as shown by the total net membership of 2789 on September 30, as compared to 2819 as of last December 31. Sufficient additions are anticipated in the next quarter to show a small gain in the membership for 1941. A detailed membership tabulation follows.

FEDERATION OF SEWAGE WORKS ASSOCIATIONS
Membership of Member Associations
September 30, 1941

Member Association	Gross Members	Dual Members	New Members and Re-instated	1940 Members Not Renewed 9/30/41
Arizona S. & W. Ass'n	26	—	10	12
California Sew. Wks. Ass'n	282	3	47	45
Central States Sew. Wks. Ass'n	486	5	81	98
Dakota W. & S. Wks. Conf.				
North Dakota	10	—	5	1
South Dakota	22	—	2	3
Federal Sew. Research Ass'n	54	—	4	14
Florida Sew. Wks. Ass'n	23	3	23	—
Georgia W. & S. Ass'n	32	—	12	7
Iowa Waste Disp. Ass'n	43	—	13	14
Kansas W. & S. Wks. Ass'n	20	—	9	10
Md.-Del. W. & S. Ass'n	25	—	6	5
Michigan Sew. Wks. Ass'n	136	—	32	32
Missouri W. & S. Conf.	5	—	2	6
New England Sew. Wks. Ass'n	189	14	20	18
New Jersey Sewage Conf.	66	—	6	8
N. Y. State Sew. Wks. Ass'n	638	22	98	93
No. Carolina Sew. Wks. Ass'n	80	—	14	14
Ohio Sew. Wks. Conf	96	—	1	11
Oklahoma W. & S. Conf.	1	—	—	—
Pacific N. W. Sew. Wks. Ass'n	73	1	22	29
Pennsylvania Sew. Wks. Ass'n	210	12	21	24
Rocky Mt. Sew. Wks. Ass'n	38	—	4	4
San. Eng. Div., Argentina Soc. Eng'rs	3	—	3	2
Sew. Div., Texas Sect., S.W.W.A.	19	—	7	16
Canadian Inst. Sew. & San.	131	—	25	17
Inst. Sew. Purif.—England	91	—	10	16
Inst. San. Engrs.—England	51	1	1	4
	2850 −61	61	478	503
Total Net Membership	2789			

Financial

In accordance with Section 5, Article IV of the By-laws, the Executive Secretary furnished each member of the Board of Control with summaries of receipts and disbursements, dated March 31, June 30 and September 30. Unaudited balance sheets were also furnished at the same time.

Acknowledgments

The Executive Secretary takes this opportunity to express gratitude for the whole-hearted cooperation of the Officers, Directors, Committees and others, which was enjoyed during the period represented by this report.

Respectfully submitted,

W. H. Wisely, *Executive Secretary*

Reviews and Abstracts

EXPERIMENTS IN SEWAGE DISPOSAL AT BIRMINGHAM

Civil Engineering (London), 36, 386 (February, 1941)

The Twenty-sixth Annual Report of the Birmingham, Tame and Rea District Drainage Board contains a considerable amount of information on the Board's activities, despite a reduction in size, due to war-time economies.

In the report for the year 1937–38 details were given of experiments then being carried out at the Minworth Works by the Water Pollution Board of the Department of Scientific and Industrial Research in conjunction with the Board. These tests are being continued in spite of war conditions, their cost being met jointly by the two Authorities. It has been established after one year's continuous working that bacteria beds used in series, with a periodic change in their order, will purify at least 50 per cent more sewage per cubic yard of medium than similar beds working singly. It is stated that even better results may be obtained in the future, and that when extensions are planned after the war, considerable savings will be effected.

Owing to the fact that several of the smaller works discharge effluent into very small streams, a high degree of treatment must be maintained at these works. At the Barston Works, near Solihull, the daily dry weather flow of 750,000 gal. forms the bulk of the receiving stream. The sewage is adequately treated in tanks and bacteria beds provided with rotary distributors. Additional purification and removal of solid matter is obtained by running the settled bacteria bed effluent on to underdrained grass land. At least once each year the grass land is allowed to dry out, and the grass, which is unfit for hay, is cut and burned.

The quality of effluent at the Board's works at Knowle has been improved by an alternative method which has been in use since September, 1938. The sewage from 2,000 population is settled in tanks and then run on underdrained grass land, which is not especially suited for the purpose because of the excessive gradient. While the effluent was satisfactory according to accepted standards, the dilution in the stream was not sufficient to prevent undesirable growths in hot weather. A pump was installed to dilute the tank effluent with three volumes of the grass land effluent, pumped back from the outfall. The volume of sewage received equals the volume of effluent, but the volume undergoing land treatment is four times as great. This procedure improved the effluent to a great extent, and since it has been in operation the objectionable growths have not appeared in the stream in hot weather.

T. L. Herrick

BIOLOGY OF MACRO-FAUNA OF HIGH-RATE DOUBLE FILTRATION PLANT

By T. B. Reynoldson

Civil Engineering (London), 36, 448 (April, 1941)

This article is an abstract of a paper which summarizes the results of an intensive and systematic study of the biology of an experimental high-rate filtration plant at the Huddersfield Corporation Sewage Works at Deighton during a period of twelve months. Further control observations were made on the routine beds at Cooper Bridge. It is pointed out that a comparison of the primary, secondary and the Cooper Bridge beds (1937–1938) show that the main effects of the high filtration rate on the primary bed was the reduction of the variation of the fauna from ten breeding species to two, and a great reduction in the total abundance of macro-fauna. Strict comparison with the Cooper Bridge beds in 1937 had been upset by the increased flow and strength of the chemical trade wastes during 1939–1940 which considerably increased the toxicity of the sewage. However, observations made on the Cooper Bridge beds during the period described in the paper showed that though the abundance of *Psychoda alternata* was very much less than previously, it was still considerably greater than on the primary bed.

In fact, the abundance was such that the usual creosote treatment was resorted to in May and June, but so below normal that further dosing was unnecessary, in contrast to the customary fortnightly dosing. The variation of the fauna on these beds had altered little.

It is concluded that, despite the peculiar character of the Huddersfield sewage, the two tendencies shown have general application, but that the rates of flow at which they will begin to appear will vary with the strength and nature of the sewage.

Under present conditions it appears that serious ponding difficulties would be encountered above a rate of 10 m.g.a.d. However, Goldthorpe (1937) showed that a daily rate of 10 and 20 m.g.a.d. could be maintained without serious ponding. This is probably explained by the increase in toxicity developed lately, some measure of which could be obtained when it was pointed out that the normal summer output of about 10,000 flies per sq. ft. (Golightly, 1937) had decreased in 1940 to a few hundred. And, in the light of the evidence given of the importance of the larvae in reducing ponding, we can account for this discrepancy.

The depression of the population of *Psychoda alternata* shown to occur in both the primary and secondary beds would seem to have considerable economic significance to any future development of the Huddersfield Corporation Sewage Works. Prevention of fly trouble has always been an important consideration but, at some cost, had been satisfactorily taken care of by the creosote treatment. A double filtration system appears to hold out considerable hope that fly control can be accomplished without treatment.

This would require careful control of the rate of flow to the primary bed to render it sufficiently unsuitable for too rapid multiplication of *Psychoda alternata,* but still remaining open, that is to say, remaining just above the point where growth accumulation is greater than its destruction by the larvae. This rate would vary with the nature and strength of the sewage. Its variation would have to be considerable to have any marked effect.

The rapid revolution of the sprayer arms and the absence of open sides to the bed would also play an important part in fly control. Fly trouble is hardly likely to be encountered in the secondary bed with present working conditions. The scarcity of food gives a most effective control to their multiplication.

T. L. Herrick

DESIGN AND OPERATION OF GRIT CHAMBERS

By A. E. Berry

The Canadian Engineer (Water and Sewage) 79, 22 (Jan., 1941)

Grit chambers are a part of almost every sewage treatment plant and they have a definite function to perform. It is doubtful, in past years, if any part of the plant received less thought in the matter of design and operation. Recently more thought has been given to the theory of operation and to means of removal and treatment and disposal of the deposited material.

Some grit will be found in all sewage. The deposition of grit in settling tanks creates unnecessary bulk and hampers sludge removal. In activated sludge systems it may be deposited in the aeration tanks and aerated channels, choking the diffuser plates. Where grit removal facilities are inadequate the cleaning task may be avoided or neglected, and grit allowed to pass on to other tanks.

The problem is to remove all reasonably coarse grit and to so handle it that it can be disposed of in a simple manner without giving offense. This latter requirement has resulted in the development of washing processes or segregation of the organic and inorganic substances.

In only the comparatively recent plants in Canada and other countries has there been deviation from the once accepted practice of providing narrow, relatively shallow tanks, with or without means for maintaining a velocity close to one foot per second. Mechanization of plants has had an important influence on grit chamber design. Equipment is now available for convenient and continuous removal of all deposited material.

The grit problem resolves itself into two steps; the removal of all silt that will be objectionable in the treatment steps that follow, and the processing and final disposal of this material. The theory of behavior of settleable solids in a liquid can be applied to grit chambers with advantage. When combined with reasonable control of velocities, the most effective sizes of the chamber can be determined to give retention of particles of any specific size.

In the theory of grit chamber operation certain principles appear to be recognized. These include the following:

(1) The larger the particle and the greater the specific gravity, the faster it settles.

(2) Particles of grit should be considered as settling at the same velocity with respect to a moving stream as in a quiescent liquid.

(3) The length of the chamber should be proportioned to its depth. Length is also associated with the area of the tank and the velocity of flow.

(4) Grit which is to be relatively free of putrescible matter will generally require washing. It should not have more than 5 per cent of putrescible material, and preferably less than 3 per cent.

Since the size and weight of the particles in sewage are important in the design of grit chambers, it is necessary to agree on a standard for the size to be removed. It appears desirable to remove all grit of the size 65 mesh (about 0.2 mm.) or larger. In some cases even smaller sizes may be extracted.

The theory of sedimentation assumes that a particle settling in a flowing stream follows a straight line. The size of the particle and the velocity of flow will then determine the distance traversed before it reaches the bottom at any fixed depth.

Regulation of velocity has been considered necessary to accomplish removal of the necessary amount of grit in the length of tank available, and to avoid depositing an excessive amount of putrescible material. Before grit washing was adopted this latter objective was the more important.

Different devices have been employed to maintain velocities reasonably close to the 1 ft. per sec. standard. Results have been disappointing. Several methods are to be seen in Canadian plants. These include multiplication of chambers, overflow weirs and orifices, and proportional weirs at the outlets. This latter method has been given some prominence at several plants.

The introduction of grit washing devices has lessened the need for close control of velocity so long as the maximum velocity is not too great. This should be about 1 ft. per second. The deposition of organic matter at low velocities is unimportant so long as it can be removed from the silt.

Grit washing by modern methods is combined with removal of the deposited material from the chamber or tank. This is done in various ways, according to the equipment on the market for the purpose. The washing usually depends on the action of the sewage as the grit travels along on inclined elevators where the motion of the water tends to remove the organic content. Here again various procedures have been devised.

It is expected that increasing use of mechanical equipment for handling and washing grit will be made. It can be said that effective means for handling grit in sewage are now available.

T. L. Herrick

SEWERAGE SYSTEMS FOR AIR TRAINING SCHOOLS

By Flight Lieutenant J. N. Langman

The Canadian Engineer (Water and Sewage), 79, 11 (March, 1941)

Under the British Commonwealth Joint Training Plan large bodies of men have been concentrated in numerous schools across the Dominion, each of which has required a sewerage system.

The systems presented both individual and collective problems, and because of the speed with which training facilities had to be arranged, were required to be designed and constructed in the minimum of time. The sites chosen were dependent on more important matters than their adaptability to the construction of sewerage systems; the majority were very flat areas of impervious soil at great distances from watercourses. Minimum grades were essential, disposal by dilution or absorption was not possible, pumping of sewage was necessary, and special equipment requiring time and plant to manufacture could not be used.

The sewer systems were constructed according to standard practices. Minimum grades were calculated for a cleansing velocity of two feet per second, when flowing full. Both concrete and vitrified pipe were used.

The manholes were of concrete construction with the contour of the sewer pipe carried through the concrete bottom. Grease skimming manholes were built on lines from garages and hangars. Storm waters were eliminated, although wash waters had to be accommodated.

Contracts were awarded with no original layout being made on the ground. A two-foot contour plan at one inch equalling 200 feet was used as a guide in making a paper location. From this quantities of trenching were estimated. No differentiation was made between rock and earth excavation; one price was to apply to the removal of all materials encountered. The above procedure was used because of the extreme shortage of time in which to carry out careful preliminary surveys.

A series of sewage treatment units were developed, a combination of which was used, depending on the type and degree of desired treatment. By preparing standard plans for each unit, with one or two dimensions omitted, both standardization and flexibility were obtained. (The paper includes eight figures which illustrate each of the units.) These standard units were as follows:

1. Septic Tank
2. Pumping Chamber
3. Siphoning Chamber
4. Trickling Filter
5. Pea-gravel Filter
6. Humus Tank
7. Chlorinating Chamber

A two compartment septic tank with standard width and depth was adopted. The length was varied to suit the size of the individual stations to provide an eight hour retention period based on 40 gallons per capita. Sludge is removed by portable pumps. Only on permanent stations were sludge pipes and drying beds provided. Here special designs were provided with the glass over type of building and underdrainage for sludge drying. It was felt that this expense was not warranted except on permanent stations.

The sump and pump house length was varied to provide a fluid capacity in the sump equal to one-fifth the volume of the septic tank. The pumps are electrically driven and are automatically float controlled. A standby gasoline pump is provided. Wherever permitted by the head a syphon chamber is provided instead of the pumping chamber.

From the pumping or siphoning chamber the sewage is discharged in batches to a trickling filter. The filters were built with a standard depth of six feet, the length and width being varied to give a dosing rate of one million gallons per acre per day. Sheeting is used to confine the stone bed, and backfill is placed around the sheeting to the level of the stone. A light frame roof is provided. It is carried by the sheeting and by supports resting on the stone.

One-inch to 2-inch stone is used. It is placed on a plank flooring laid on natural earth, with a slope to a catch basin in the center. The septic tank effluent is distributed over the stone bed by a series of wooded troughs carefully leveled.

The filter effluent is discharged to a covered humus tank which has one quarter the fluid capacity of the septic tank. It is built of reinforced concrete. Solids are removed by pumping.

The humus tank effluent is passed through a pea-gravel filter. In each case the area of this unit is one-quarter of that of the trickling filter. The sewage is applied through rows of 4 in. field tile spaced on 18 in. centers, with ½ in. space between each tile. The crown of the tile is flush with the stone surface. The under drainage system is similar to the distributing system except that the rows are on 3 ft. centers. They are placed in shallow trenches, the bottoms of which are 2 ft. below the stone surface. The entire unit is placed in an earth excavation and covered by an 18 in. earth fill.

The effluent from the pea-gravel filter passes through a chlorine contact chamber. A fifteen minute retention period is used. Ten parts of chlorine are added by means of solution feed equipment.

The cost of individual units to accommodate 40,000 gallons per day is as follows:

1. Septic tank	$1,300
2. Siphoning chamber	350
3. Pumping chamber	2,500
4. Trickling filter	2,000
5. Humus tank	500
6. Pea-gravel filter	200
7. Chlorinating chamber	1,150
Total—without pumping	$5,500
Total—with pumping	$7,650

T. L. Herrick

SOME VIEWS AND EXPERIENCES ON THE TREATMENT OF TRADES WASTES

By M. E. D. Windridge

The Surveyor, 99, 297–299 (May 2, 1941; 99, 315–316 (May 9, 1941)

The author cites the obligation of municipal or other authorities to receive and deal with trade wastes as defined in the Public Health (Drainage of Trade Premises) Act of 1937. Wartime conditions have prohibited many sewage plant extensions which otherwise would have been constructed by the authorities treating trade wastes as required by the Act. The author suggests that the present conditions offer opportunity for study of the trade wastes problems and working out of methods of handling the same. The following items are discussed: (*a*) flow and composition of trade wastes, (*b*) pre-treatment, (*c*) balancing of flow, (*d*) neutralization, (*e*) regulation of temperature discharge, (*f*) artificial silk wastes, (*g*) board mill wastes, (*h*) gas liquors, (*i*) milk wastes, and (*j*) yeast wastes.

It is expected that the application of the Act will greatly increase the number of sewage treatment plants in England.

K. V. Hill

PRACTICAL PROBLEMS OF SEWAGE WORKS MANAGEMENT

The Surveyor, 99, 325–326 (May 16, 1941); 99, 337–338 (May 23, 1941)

These two articles present some of the discussion at a branch meeting symposium of the Institute of Sewage Purification. The subjects discussed were septic sewage, low temperature in digestion tanks, deposit in heater tubes, disintegration of concrete, and heat exchanger working.

Septic sewage was due to the action of anaerobic organisms, mainly saprogenic, which had the power of splitting complex proteins and cellulose into simpler substances. Proteins were changed to albuminoses to peptones, amino-acids, amines, ammonia and free nitrogen. Nitrogenous-cellulose compounds were split up into hydrogen, hydrogen-sulfide, carbon-dioxide, methane and ammonia. Dilution of septic sewage with river water had been practised at Bedford successfully.

Low temperature in an exposed concrete digestion tank was thought to be due to heat loss through the tank. Insulation of the tank wall did not maintain the higher temperature sought. Investigation of the tank showed that the heating coils were coated with a 3 in. layer of sludge scale. The moral—unless heat was put into the tank, no amount of insulation would maintain a high temperature in the tank.

Deposit in heater tubes (using supernatant liquor from the secondary digestion tanks and passing it through a tubular heater) was due to sludge, matches, fibre and crystals of magnesium ammonium phosphate. Passing the supernatant liquor upwards through a tank equipped with a straining device had eliminated materials likely to clog the tubes. Loss of carbon dioxide, due to heating sludge liquors in which calcium, magnesium and ammonium bicarbonates were present, was likely to cause deposits.

At Coventry, hydrogen sulfide gas evolved from artificial silk wastes caused considerable disintegration of concrete in sewer manholes. Remedial measures comprised the use of aluminous and acid-resisting cement in concrete and mortar.

Steel tubes in a heat exchanger becoming perforated due to the action of the cooking water (in four years) were replaced by arsenical brass tubes which, after two years, were clean inside and only slightly scaled outside. High velocity and a temperature below 85 deg. F. were believed necessary to avoid scale formation inside the tubes.

K. V. Hill

BOOK REVIEWS

Sanitary Engineering. By Harry G. Payrow. 483 pages. International Textbook Company, Scranton, Pa. Price, $4.00.

The author is Assistant Professor of Sanitary Engineering at Lehigh University. The book deals with stream flow, water supply, water treatment and distribution in the first 279 pages; and sewerage, sewage treatment and industrial wastes in the following 196 pages. The sewage section is rather inadequate as a textbook even for undergraduates as it is concerned mainly with novelties or recent manufacturers' products, and the fundamental bases of sewage treatment are too briefly discussed. Most of the illustrations are taken from manufacturers' bulletins. The students who use this book receive little benefit of discriminating selection of material by the author. However, they will at least be up-to-date and possibly the water section may be more conservative and fundamental.

Analytical Chemistry of Industrial Poisons, Hazards and Solvents. By M. B. Jacobs. 636 pages. Interscience Publishers, Inc., 215 Fourth St., New York, N. Y. Price, $7.00.

This is a remarkable book, the first in a series of monographs on analytical chemistry and its applications. The author, formerly with the U. S. Food and Drug Administration and later the Department of Health of New York City, displays remarkable erudition in his field. The book is a veritable encyclopedia on war gases, industrial poisons, dusts and harmful metals. Methods of sampling and analysis are given in great detail, but the book is of far more value than the usual book on analytical chemistry because it includes broad discussion of the significance and physiological effect of all conceivable poisons and toxic substances. It is of particularly timely value now when so much discussion is heard in technical societies of poison or war gas hazards. This book covers the subject so exhaustively and authoritatively that no further search for information is necessary. There is a wealth of information of value to the sewage works operator interested in toxic gases and hazards.

Principles of Sewage Treatment. By Willem Rudolfs. 128 pages. Published by National Lime Association, Washington, D. C. Price, 50 cents.

Dr. Rudolfs has written a very interesting booklet, in which he hardly mentions the use of lime in sewage treatment, so the reader need not be concerned that it may contain subtle propaganda for the National Lime Association. The chapters are: reasons for sewage treatment, sources of sewage, composition, microbiology, stabilization of sewage, methods of treatment, sludge treatment and disposal, chlorination, plant operation, and methods of sewage analysis. All the fundamentals of sewage disposal are presented with discrimination and distinction, yet the text is clear and simple enough to be understandable and interesting to the average man interested in science and sanitation.

It is to be hoped that copies of this valuable work are still available.

F. W. Mohlman.

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F. W. Mohlman

Executive Secretary:
W. H. Wisely

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Author Index

Sewage Works Journal, Volume XIII, 1941

ARTICLES

OPERATORS' REPORTS AND SUGGESTIONS

REVIEWS AND ABSTRACTS

Subject Index

Sewage Works Journal, Volume XIII, 1941

ARTICLES

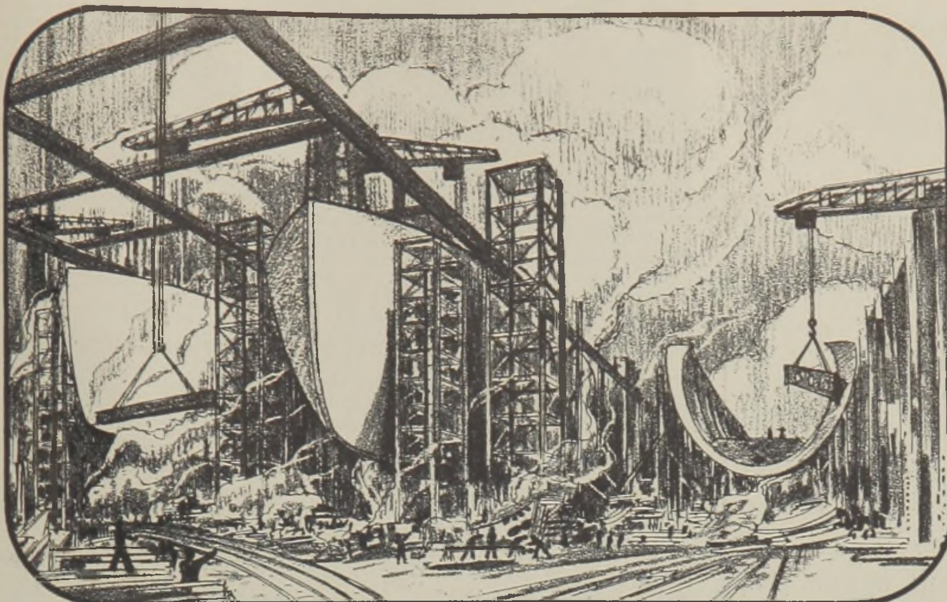
EDITORIALS

FEDERATION AFFAIRS

PROCEEDINGS OF LOCAL ASSOCIATIONS

REVIEWS AND ABSTRACTS

ADVERTISERS' CONTRIBUTIONS



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   The spiral, cross-sectional flow induced by the shape of the basin continually carries the coarse material to the revolving drum.

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COMPLETE DIMENSIONED LAYOUTS AND SEWER FLOW CURVES IN BULLETIN 185-A

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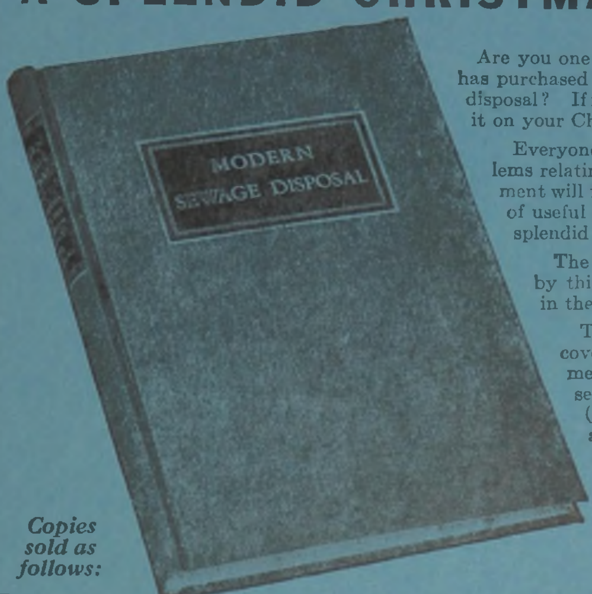

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